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NUCLEAR WEAPONS AND PROTECTION AGAINST NUCLEAR WEAPONS

By

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[Text] Foreword

In a series of imperialist countries, especially in the United States, nuclear weapons are being further developed, new delivery vehicles are being created and are being introduced into the armies regardless of all protests of peace-loving humanity. Stockpiles of nuclear charges are being increased and are constantly kept in readiness in arsenals of the armed forces.

Contrary to the specific proposals by the Soviet Union and other socialist states during the disarmament negotiations concerning a universal ban on the manufacture, stockpiling, and use of nuclear weapons, the United States and some other imperialist countries so far have declared themselves only ready to enter into certain partial agreements in some fields.

In case a war should be unleashed against the socialist states and in case of other wars, the United States is still threatening to use nuclear weapons. In this connection, detailed instructions were drafted regarding the authority of NATO unit commanders for nuclear weapons employment and a "theory of escalation" of weapons employment was devised.

As far as our units are concerned, this creates the need for devoting undiminished attention to nuclear defense measures during training.

This textbook takes up the most important combat properties and destructive effects of nuclear weapons and from that we derive and explain the necessary unit nuclear defense measures. This book is designed for study at the "Friedrich Engels" Military Academy and other college installations under the Ministry of National Defense, for individual independent study by officers of the various armed agencies and other interested parties. It cannot and should not replace the service regulations concerning these areas. Its objective instead is to support the study of theoretical basic problems of nuclear weapons and nuclear weapons defense through systematic and as realistic as possible illustration for the group of readers who, in their work, will primarily have to come to grips with semistrategic and tactical problems. This is why a strict dividing line was drawn in the selection of the subject matter. The individual problems and situations were identified in keeping with their significance through differing description. Both with the help of the reference notes given with each chapter and with the help of the large bibliography it was made possible quickly to gain access to special problems. The review questions included in the individual chapters can serve as guidance for the main points to be covered especially during individual independent study.

It will be the job of all officers working with this book to contribute to its further improvement by passing on critical comments and lessons learned.

Lieutenant General Prof. Wiesner

0. Introduction

So long as imperialism exists, there is the danger that aggression might be unleashed against the socialist states.

For the sake of the reliable protection of further socialist construction and to guarantee peace in Europe, the National People's Army must during every development phase have the necessary high level of combat readiness and it must be prepared, together with the Soviet Army and the other brother armies of the states of the Warsaw Treaty effectively to counter any possible aggression and to wipe the aggressor out on his own territory.

In keeping with the NATO concept and the plans of the imperialist circles in the FRG, we must expect that aggression might begin both as a concealed or limited war or as a general nuclear war.

A war involving the use of nuclear weapons would create the very highest requirements for the troops among all of the possible variants of a possible armed conflict.

"All this makes it obvious for us to conclude that the armed forces of the Soviet Union and the other socialist countries must primarily prepare for a war in which both states (the United States and the Soviet Union--the author) will make massive use of nuclear weapons. This is why one must consider the scientific solution of all theoretical and practical problems, which arise from the preparation for such a war and its conduct, as the primary mission here."[1]

Developments in the nuclear weapons field are characterized not only by the steady increase in stockpiles of nuclear charges by the nuclear powers but also by the further perfection and creation of new systems for their employment and the rapid introduction of these systems into the armed forces.

The detonation equivalents have grown from the kiloton range to the Megaton range. Here, the scale of payloads and delivery vehicles extends from missiles via airplanes and various artillery systems to nuclear mines.

This equipment of the armed forces with the most varied kinds of nuclear devices took place within the overall context of the revolution in military affairs, the new equipment and re-equipment of the armed forces and their reorganization, the drafting of a military doctrine and art of war which will do justice to the requirements of a possible worldwide nuclear missile war, the drafting of new combat regulations, etc., whereby nuclear weapons represent not only the most essential element but also the cause of many other upheavels in the military-science and military-engineering field--and not here alone either.

By virtue of their annihilating and destructive effects, nuclear weapons by far not only exceed all previously known means of annihilation but also differ from them qualitatively. Here the effects of a nuclear weapon are very manifold and they depend in each case on the specific conditions of the

particular detonation. A nuclear weapons detonation is characterized by the fact that, in addition to the immediately effective annihilation factors, there can also be extensive aftereffects in the form of crater formation and the radioactive contamination of the terrain. As a result of massive nuclear strikes, especially following surface and underground detonations, there are vast areas which are destroyed and which are radioactively contaminated with high dose exposures; they can exert universal influence on the preparation, the course, and the outcome of combat operations and they can have an essential effect on the work of the various headquarters, the actions of the troops, and measures to provide backup support for combat and operations.

The planning, organization, and implementation of nuclear weapons defense for the units in the field requires commanders and staffs to have comprehensive tactical-semistragetic and natural-science-technical knowledge and creates the very highest requirements for the unit command as such. Nuclear defense is an integrated component of unit defense against mass annihilation weapons.

In all types of combat and in any situation, this nuclear defense must be organized with the objective of diminishing the effects of enemy nuclear weapons employment to the maximum extent, preserving the combat value and combat readiness of our troops, or restoring them quickly after nuclear strikes by correcting the consequences and guaranteeing the accomplishment of the assigned mission.

Unit nuclear defense is essentially achieved through the following:

Timely reconnaissance of enemy preparations for the use of nuclear weapons and the prevention of the employment of such weapons;

Advance determination of radioactively contaminated areas as well as the precise indication of areas in which there will be extensive destruction, fires, or floods resulting from the use of nuclear weapons;

Constant nuclear radiation monitoring;

Timely warnings for the troops and for rear-echelon support units concerning radioactive contamination;

Decentralization and camouflage of field units and rear-echelon support units;

Alternation of unit bivouac areas;

The use of individual protective gear as well as the utilization of the protective properties of combat vehicles, the terrain, and cover;

Preparation of roads for maneuvers and for Engineer-level improvement of areas to be taken up by the troops;

Effective and efficient action in contaminated areas;

Dosimetry and nuclear radiation monitoring in the platoons and companies;

Timely and steady supply of units with protective equipment;

Rapid elimination of the consequences of enemy nuclear strikes.

1. Classification, History, and Structure of Nuclear Weapons

1.1. Principles of Subdivision and Fundamental Concept Definitions

Nuclear weapons are mass annihilation weapons. At this time there are three major groups of mass annihilation weapons: Nuclear weapons, chemical weapons (CW agents), and biological weapons (BW agents).[2]

The essence of mass annihilation weapons consists in the fact that their injuring or destructive effects always extend to a more or less large and continuous surface area, that, compared to the means of application, tremendous effects are produced, and that the effects of their employment as a rule cannot be confined only to the militarily necessary degree.

Each group of mass annihilation weapons has specific combat properties and annihilation effects. This is why the determination of a clear sequence is hardly possible. Nevertheless, nuclear weapons hold primacy inasmuch as they are not directed practically exclusively against human beings, such as chemical and biological weapons, but rather produce heavy destruction of combat equipment, buildings, installations, etc.

The general concept of "nuclear weapons" encompasses all types of weapons whose annihilating and destructive effects are based on the release of nuclear energy.

It is basically possible, first of all, through certain unguided nuclear reactions to release nuclear energy in the form of a detonation and, besides, to utilize the nuclear radiation, which is released as a result of the decay of natural or artificial radionuclides, as the sole annihilation factor.

Detonating nuclear weapons are weapons in which the release of energy is based on the foundation of nuclear fission and/or nuclear synthesis reactions in the form of detonations. Radioactive warfare agents are radionuclides which have been assembled especially for wartime use; they can be employed in various aggregate states and with different means and methods.

In the following we will use the term nuclear weapon always in the sense of "detonating nuclear weapon" while on the other hand we will be speaking of radioactive warfare agents.

Nuclear weapons can be arranged according to a series of viewpoints:

According to the type of energy released;

According to the detonation intensity (the detonation equivalent);

According to the type of nuclear charge employed;

According to the military purpose or the devices used.

Concerning the basic schemes of energy release, we can basically distinguish nuclear fission weapons and nuclear synthesis weapons.

Nuclear fission weapons are nuclear weapons in which the detonation energy is produced by the fission of heavy, energy-rich nuclei into heavy nuclei which are poorer in energy, in the process of thermonuclear reactions.

In keeping with the course and type of energy release, we can furthermore distinguish between single-phase and multi-phase nuclear weapons.

The term single-phase nuclear weapons is applied to those nuclear weapons where the energy release is based either only on nuclear fission or only on nuclear synthesis.

Multi-phase nuclear weapons are nuclear weapons where the detonation energy is released in succession through nuclear fission and nuclear synthesis reaction in two or three phases (nuclear fission--nuclear synthesis--nuclear fission).

Nuclear fission weapons and nuclear synthesis weapons thus are single-phase nuclear weapons corresponding to the concept definitions given here.

In using the terms mentioned we must keep in mind that no uniform terminology has so far prevailed both in military language and in the pertinent literature. For example, in place of the concept of multi-phase nuclear weapon we still frequently have the concept of nuclear synthesis weapon or thermonuclear weapons although the energy from these nuclear weapons does not exclusively stem from nuclear synthesis.[3]

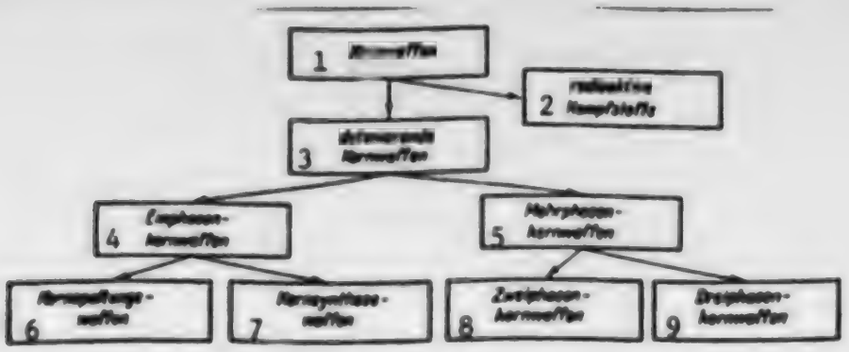


Figure 1.1. Classification of nuclear weapons in accordance with energy release. Key: 1--Nuclear weapons; 2--Radioactive warfare agents; 3--Detonating nuclear weapons; 4--Single-phase nuclear weapons; 5--Multi-phase nuclear weapons; 6--Nuclear fission weapons; 7--Nuclear synthesis weapons; 8--Two-phase nuclear weapons; 9--Three-phase nuclear weapons.

The detonation intensity is the most important characteristic of nuclear weapons.

The detonation intensity is a measure of the total energy released as a result of the detonation. It is given in equivalents (t, kt, Mt) of Trinitrotoluene (TNT).

In all formulas given in this book, the detonation intensity is always to be inserted in terms of kt TNT.

The detonation intensity of presently available nuclear weapons is roughly within the limits of 0.005 kt TNT to 100 Mt TNT.

This means that connection downward is established to the calibers of conventional ammunition. Upward, a further increase in the detonation intensity is physically and technically conceivable but militarily hardly meaningful.

We can schematically subdivide nuclear weapons as follows, as a function of the detonation intensity:

Small detonation intensities:	$q \leq 15$ kt TNT
Medium detonation intensities:	15 kt TNT $< q \leq$ 100 kt TNT
Large detonation intensities:	100 kt TNT $< q \leq$ 500 kt TNT
King-size detonation intensities:	$q >$ 500 kt TNT

The nuclear weapons criminally employed against Hiroshima and Nagasaki by the American imperialists in 1945 had a trotyl equivalent of about 20 kt. This detonation intensity is often used as a comparison value and is therefore referred to as the "standard bomb."

A detonation intensity of 100 Mt TNT implies an increase in the detonation energy at a ratio of 1:5,000.

In this kind of estimate one must however keep in mind that the annihilation radii do not grow simply in proportion to the detonation intensity but increase considerably more slowly. On top of that we furthermore have the fact that the detonation intensity, expressed in trotyl equivalents, is only a measure of the magnitude of the total energy released during a detonation whereas regarding the distribution of that energy over the individual annihilation factors, no simple comparison to conventional ammunition is possible.[4]

In purely physical terms, a smooth transition is possible in the range of detonation intensities mentioned here. Considering the tactical-technical data on nuclear weapons devices, we however get certain standard detonation intensities which make it possible to evaluate the consequences of enemy nuclear weapons strikes.

The type of nuclear charge used likewise does influence the characteristic of a nuclear weapon.

The radionuclides U-235 and Pu-239 are used mostly in nuclear fission weapons.

The hydrogen isotopes deuterium and tritium are used--mostly in the form of lithium compounds--in nuclear synthesis weapons or in multi-phase nuclear weapons.

U-238 is used for the release of nuclear fission energy by means of super-fast neutrons.

The nuclides that can be used for nuclear fission differ essentially in terms of their critical parameters. For example, the size of the critical charge mass of Pu-239 is only about 25 percent of that of U-235.

This necessarily results in differentiated design principles for the individual nuclear weapons types. On top of that we have the fact that nuclear explosives also differ greatly in terms of their miscellaneous physical and chemical properties. Something similar applies to nuclear synthesis materials. Here, for example, the aggregate state, in which they are normally present, plays a very great role. Another viewpoint is derived from the differing ignition temperature and the resultant highly variable course of thermonuclear processes as a function of the composition of the nuclear synthesis charge.

Some other viewpoints will be covered in greater detail in connection with the individual nuclear weapons types.

By way of guidance we might estimate that nuclear fission weapons of up to about 300 kt TNT can probably be made. In practice however the upper limit would be around 100 kt TNT. Two-phase nuclear weapons (addition of nuclear synthesis material) are best suited for detonation intensities of several hundred kt TNT. Nuclear weapons in the Mt range are most probably based on the three-phase principle. But it is also possible to bring about very great detonation intensities with a high nuclear synthesis share. Conclusions can be derived from several test series.

The means of delivering a nuclear charge to a target are very manifold. At the end of World War II and during the years immediately thereafter, nuclear weapons existed practically only in the form of bombs. Today, nuclear charges are delivered primarily by missiles. The combination of missile and nuclear weapon, the nuclear missile, represents a completely new quality of fire. It forges the technical character of a possible world war as a nuclear missile war. Prior development of weapons in engineering terms as well as nuclear warheads, as delivery vehicles or devices, makes it possible today to use nuclear weapons universally, over any desired range, against the most varied targets under all meteorological conditions.

Nuclear weapons can be used by all services. Specifically, they can be used in the following ways (some of the NATO devices are given in parentheses):

Ground-to-ground missiles for tactical, semistrategic, and strategic uses, with nuclear charge ("Lance"--up to 70 km, "Sergeant"--up to 140 km, "Pershing" --up to 740 km, "Minuteman"--up to 13,000 km);

Ground-to-air missiles (AA missiles to engage manned and unmanned air attack systems, ABM's) with nuclear charge ("Nike-Hercules"--30 km altitude);

Aircraft (nuclear bombs and air-to-ground missiles with nuclear payload) ("F 84 F Thunderstreak," "F-100 D Super Sabre," "F-4 C Phantom," "HSD Blue Steel" air-to-ground missile--up to 320 km after firing from aircraft);

Conventional artillery pieces (roughly from 150 mm on up) in the form of nuclear shells (155-mm SP howitzer, M-109, up to 18 km, 203.2-mm SP howitzer, M-110, up to 16 km);

Submarines, especially nuclear-powered, in the form of underwater--ground missiles with nuclear charge or torpedoes with nuclear charge ("Polaris" --up to 4,000 km);

Surface vessels with corresponding missile or torpedo armament;

Nuclear mines used by ground forces and naval forces;

Outer space systems.

The means for the employment of nuclear weapons to accomplish strategic assignments above all include intercontinental missiles, long-range missiles, but also medium-range rockets, strategic air units, and submarines as well as outer space weapons. Here one uses primarily nuclear weapons with detonation equivalents on the order of magnitude of several hundred kt TNT up to several tens of Mt TNT.

In the semistrategic-tactical context, short-range and medium-range rockets, fighter-bomber units, certain artillery systems, and mines are especially used as nuclear weapons.

Ground forces operations can partly be supported along the coastline through nuclear weapons employed by naval forces. The detonation intensities of semistrategic-tactical nuclear weapons as a rule cover a range extending from several kt TNT to several hundred kt TNT.

One special aspect of nuclear weapons development in recent years consists in the fact that the transition to multiple nuclear charges was accomplished especially in the strategic systems. In this way, several nuclear warheads can be aimed against one or several targets with a single delivery vehicle.

Although examples of this type become obsolete very quickly, we might mention here the American MRV and MIRV series systems. In the MRV system, for example, just one missile of the Polaris A-3 type can carry three nuclear warheads which, after their separation from the booster, reach their target in a ballistic form.

In the case of the MIRV system, the individual nuclear charges have an additional engine of their own and are used in a program-controlled manner against individual targets within a radius of up to 200 km.

The "Minuteman" can thus carry three nuclear warheads at 200 kt TNT, each, while the "Poseidon" can carry ten nuclear warheads at 50 kt TNT, each, including as many as four decoys.[5]

The most effective nuclear defense measure consists in annihilating enemy nuclear weapons systems before they are in a position to use nuclear weapons.

This goal requires specific knowledge of the employment principles of enemy nuclear weapons, their storage, movement, supply, etc., their constant observation and a readiness immediately to engage them after the appearance of such a target, using all available means, especially the systems of the rocket forces and the artillery on duty.

As we hinted earlier, nuclear weapons systems are constantly changing. Because, other things being equal, the annihilation effects of a nuclear weapon are relatively independent of the delivery vehicles, questions connected with that will not be subjected to any further consideration below.

Review Questions

1.1. What viewpoints must be considered in the concept definition of mass annihilation weapons?

1.2. What are the characteristics according to which we can arrange nuclear weapons and what practical conclusions can be drawn from that?

1.3. Why is the detonation intensity of a nuclear weapon not simply comparable to the effect of conventional weapons?

1.4. What kinds of nuclear weapons systems are presently available to NATO and what are the resultant conclusions concerning unit nuclear defense?

1.5. What is the most important nuclear defense measure and how can it be implemented.

1.2. The Most Important Stages in the History of Nuclear Weapons

The physical, chemical, and engineering prerequisites for the creation of nuclear weapons in the middle of this century were the numerous outstanding results from the natural sciences, especially atomic and nuclear physics, and the very highly-developed industry in the Soviet Union and in the leading imperialist countries.

The actual early history of nuclear weapons begins in December 1938 with the discovery of atomic nuclear fission through the action of neutrons by the German physicist Otto Hahn.

Theoretical studies conducted after this discovery already in 1939 revealed that tremendous quantities of energy could be obtained on the basis of nuclear fission under certain prerequisites. Until that time, by far most of the physicists were of the opinion that practical utilization of nuclear energy was not possible because the energy amount to be used for nuclear conversion was greater than the amount released as a result.

Hahn's discovery put the entire situation into a completely new light.

If we look at the international political situation at that point in time, we can understand that all further publications were suddenly cut off. In secret however physicists in a whole series of countries looked into the phenomenon of nuclear fission and also tried to fathom the resultant consequences.

These consequences could indeed be monstrous because after all German fascism was already getting ready to implement its aggressive goals by unleashing a world war.

In the United States, a group of scientists, headed by L. Szilard, persuaded Albert Einstein to contact President F. Roosevelt and to explain to him the military significance of the discovery of nuclear fission through neutrons and to propose the conduct of secret research.

Practical work on the "Manhattan Project" finally began in August 1942. This was the code name for all scientific, technical, military, and administrative measures which in the end were supposed to lead to the construction of a nuclear bomb and its employment.

During the 1940's, the United States had become a stronghold of nuclear physics. A. Einstein had emigrated from Germany while E. Fermi and E. Segre had come from fascist Italy. Nils Bohr came from Denmark. On the basis of this tremendous scientific capacity, backed up by a highly-efficient, undestroyed industry, work quickly progressed in spite of tremendous natural-science and technical difficulties. Los Alamos, the R. Oppenheimer laboratory, became the center for the design and construction of the bomb.

In addition to those already mentioned, Oppenheimer had working with him such well-known scientists as E. O. Lawrence, J. Dunning, and H. Bethe.

To obtain the necessary nuclear explosive, efforts were relatively quickly concentrated on three of the original five methods contemplated.

On 2 December 1942, Fermi recorded the first chain reaction in the graphite pile built by him.

On the basis of lessons learned until then, four big breeder reactors were built in Hanford, Washington, to produce Pu-239. The first plutonium shipment went to Los Alamos in January 1945.

Huge installations for the separation of the uranium isotope U-235 (share 0.7 percent) were built in Oak Ridge, Tennessee. A gaseous diffusion plant and an electromagnetic separation plant were built. The gaseous diffusion plant began to operate in January 1945 (at a cost of more than M1 billion); the enriched U-235 was then further processed in the electromagnetic plant so that an adequate quantity of U-235 was likewise ready for shipment to Los Alamos in June 1945.

By the middle of the year, the United States finally had three "atomic bombs." The sum of $2 billion was invested to attain this goal.

The first experimental detonation of a nuclear fission bomb based on the implosion principle took place at 0530 on 16 July 1945 at the Alamogordo Air Base in New Mexico. The detonation intensity of the 214-t experimental device, which was set off on a 30-m high steel tower, was 10 kt.

This first experimental detonation was followed on 6 and 9 August 1945 by the senseless and criminal bombing by the American imperialists on the two Japanese cities of Hiroshima and Nagasaki.

The nuclear detonations caused fearful losses among the defenseless and unknowing population.

Table 1.1. Effects of Nuclear Bombs Dropped on Hiroshima and Nagasaki[7]

		Hiroshima	Nagasaki
1	Gesamtbevölkerung	300000	200000
2	Bevölkerungsdichte je km²	14000	25000
3	Tote	80000	40000
4	Verletzte	70000	40000
5	sofortige Erste Hilfe brauchten	85000	50000
6	Todesrate je zerstörten km²	6000	8000

Key: 1--Total population; 2--Population density per km^2; 3--Dead; 4--Injured; 5--The following required first aid; 6--Death rate per km^2 destroyed.

Other figures were given in various publications. This is due to the fact that, because of wartime events, no precise data were available on the population statistics for both cities; besides, it is very frequently impossible to determine under what conditions the loss estimates were made.[8]

The size of the total area destroyed in Hiroshima was about 12 km^2 and in Nagasaki it was about 5 km^2.

The report by the United States Strategic Bombing Survey[9] among other things contains the following passage on the Hiroshima and Nagasaki raids: "A single atomic bomb was detonated at 0815 (0915 local time, Tinian time--the Author) on 6 August 1945 over Hiroshima. Most industrial workers had already started work but many were still on their way; almost all school children were busy putting up firebreaks or moving valuables out into the country.

"The raid took place 45 minutes after a prior all-clear. Because no air raid alarm was sounded and because the population in view of the few aircraft did not feel particularly worried, the detonation came as an almost complete surprise. Most people were taken by surprise out in the open or at home. The bomb blew up somewhat northwest of the city center. Because of the accurate bombing, the level terrain, and the circular layout of the city, Hiroshima was

devasted uniformly and comprehensively. The entirely heavily built-up part of the city was practically levelled to the ground due to blast and fire. A firestorm arose. And, 3 days later, Nagasaki was hardly any better prepared. The day was clear, there was almost no wind--a usual summer day. The continuing air raids against the population of the city and the harshness of the summer led to a certain neglect of air raid protection measures. The preliminary alert was sounded at 0748 and it was followed by the alarm as such at 0750; the all-clear was sounded at 0830 and the population's alertness yielded to a great feeling of calm. The city continued on the alert; but the air raid alarm was not sounded immediately when two aircraft of the B-29 type were sighted once again. The bomb was dropped at 1102 and the alert was not sounded until 1109. Only 400 persons were in the air raid shelters. At ground zero, almost everything had been levelled to the ground; no further reports came from that area immediately after the detonation."

In his memoirs, which were published in 1956, Truman--who as President of the United States at that time ordered the nuclear bombs to be dropped on the two cities of Hiroshima and Nagasaki--wrote the following: "In 1945, there took place so significant an event that our relations with the entire world were basically changed and that a new era was announced to mankind, an era whose consequences, as well as the objectives and problems it raised, we still cannot fully gauge at this time. This event is the production of the atomic bomb."[11]

What, in the view of American imperialism, was the essential content of these new relations?

Yesterday as today the imperialist circles in the United States try to explain that the rapid development of the American nuclear weapons system was necessary to get ahead of fascist Germany and that the use of the nuclear bombs against Japan supposedly forced that country into rapid capitulation and thus put an end to World War II.

If we follow the rational core of the investigations by D. Irving[12] concerning research in the field of nuclear weapons in fascist Germany and in the United States during World War II, we may, in the light of present-day knowledge, admit that some of the scientists involved in the Manhattan Project in their work were guided by concern over the fate of humanity threatened by fascism.

But this approach is only half the truth. Very soon, those scientists lost every right to have any say on the use of their work results.

Concerning Japan's capitulation, it was speeded up inasmuch as certain circles in the Japanese government which were inclined toward capitulation in this way with renewed clarity received a demonstration of the hopelessness of the military situation. This capitulation however in the final analysis was the result of the Soviet Union's entry into the war against Japan and the smashing of the main body of the Japanese army, the Kwantung army, in Manchuria. This clearly shows that the leading circles in the United States were quickly concerned with testing the new weapon under "specific" conditions and thus to tackle far-ranging political objectives.

The British physicist Blackett mentions these objectives as he writes that "dropping the atomic bombs was not so much the last military act of World War II but rather one of the first major operations in the cold diplomatic war against the Soviet Union."[14]

In view of the effects of these detonations, the leading circles in America at that time adopted the mistaken belief that "by threatening to use the atomic bomb, it would be possible to force the Soviet Union--no more and no less-- to drop socialism and to restore capitalism."[14]

It thus becomes clear with brutal openness that it was not so much America's fear of having Hitler Germany get ahead of it in the production of the first nuclear weapons which caused the American effort to make a maximum effort but rather from the very beginning the endeavor to use this new weapon as a means of threatening and blackmail and thus to carry out the United States' plans for world rule.[15]

Former President Truman did not feel any remorse later on over the fact that he gave the order to wipe out more than a hundred thousand innocent people in Hiroshima and Nagasaki. Early in November 1961 he made the hideous statement in addressing the National Press Club in Washington to the effect that he would at any time repeat the order to drop atomic bombs on both of these Japanese cities.[16]

The trotyl equivalent of each of the two nuclear bombs dropped on Hiroshima and Nagasaki was about 200 kt (20,000 t). But the previously mentioned report by the United States Strategic Bombing Survey shows that formal comparisons make little sense. Here we find the following calculations: "On the basis of the known destructive power of various bombs and on the basis of experiments, the bombing survey figured out what bomb load would have been necessary to cause the same destruction in Hiroshima and Nagasaki. In Hiroshima, it would have been necessary to drop 1,300 t of bombs (consisting of one quarter He and three quarters of incendiary bombs) and in Nagasaki it would have been necessary to drop 600 t bombs (three quarters He and one quarter incendiary bombs). Besides, in Hiroshima, 500 t of fragmentation bombs and in Nagasaki 300 t of fragmentation bombs would have been necessary to cause similar human losses. The total bomb load thus would have been as follows: 1,800 t in Hiroshima and 900 t in Nagasaki. If each aircraft carries 10 t, then we would have had to send 180 B-29 bombers against Hiroshima and 90 B-29 bombers against Nagasaki."[17]

The nuclear payload came to about 50 kg both in the Hiroshima bomb (U-235, "gun principle") and in the Nagasaki bomb (Pu-239, implosion principle).

The energy balance shows that, of that amount, about 1 kg were split in each case and that the efficiency thus was 2 percent.

The total weight of each nuclear bomb (including bomb carrier, chute, etc.) was about 5 t. The detonation altitudes were at 600 m or 350 m.

The nuclear armament effort of the United States did not terminate or was not slowed down upon Japan's capitulation and the end of World War II; instead,

it assumed unimaginable proportions. Huge armament industry plants were built and hundreds of thousands of people were employed in them. The United States had a nuclear weapons monopoly and used it as a weapon in the Cold War. With all available means, the United States tried to perfect nuclear weapons and to establish corresponding stockpiles in order to give its policy of strength the necessary emphasis against the Soviet Union. That goal was also served by renewed nuclear weapons tests. The so-called "Abel Bomb" was exploded on 1 July 1946 at an altitude of 500 m between the aircraft carrier "Independence" and a Japanese cruiser as the first surface detonation over water.

The second test followed in the region of Bikini Atoll on 25 July 1946; this was an underwater detonation.

This development was naturally watched very carefully by the Soviet Union. Based on the advantages of the socialist social system, the CPSU and the Soviet government mobilized all available scientific and technical capacities in order to be able to begin with the development, manufacture, and testing of nuclear weapons.

Looking back, A. P. Aleksandrov writes the following on this: "I. V. Kurchatov and the other scientists, engineers, and experts from the most varied fields --who worked on the Soviet atomic project by order of the Central Committee of the CPSU--clearly realized that the development of an equivalent weapon-- even before the United States had gone into the mass production of atomic weapons--was a question of life or death for the defense of the Soviet Union."[18]

In the summer of 1939, the Soviet physicists Ye. B. Zeldovich and Ye. B. Kharitov provided theoretical proof to the effect that the chain reaction of nuclear fission was real and in this way they created certain foundations for the theory of the chain reaction.

In the autumn of 1940, I. V. Kurchatov made a general analysis of the possibilities of bringing about a chain reaction and in the process recognized the enormous difficulties which would stand in the way of practical implementation.

Back in 1939, he had already contacted the Soviet government with a reference on the military problems involved in nuclear fission. The fascist attack on the Soviet Union led to the destruction or evacuation of the laboratories in Kharkov and Leningrad. Moreover, the military situation forced the leading Soviet scientists to devote themselves to the immediate perfection of equipment for the Soviet armed forces.

With the turning point in the Great Fatherland War of the Soviet Union, scientific research then began in the field of uranium fission in 1942. A central study group was created in Moscow in 1943 under the direction of I. V. Kurchatov. The theory of nuclear reactors was developed already in the autumn of 1943 and the first Soviet uranium-graphite experimental reactor became operational on 25 December 1946. In addition to I. V. Kurchatov, the following of his closest collaborators participated in this outstanding event: I. S.

Panayuk, B. G. Dubrovskiy, Ye. N. Babulevich, and A. K. Kondratev. This meant that the "secret" of the production of plutonium, the nuclear explosive, had been discovered.

Parallel to this scientific effort, an efficient nuclear industry was planned and built up. While the imperialist circles in the United States figured on the Soviets getting their first nuclear weapon at the earliest in 1952, the then Soviet Minister Molotov was able to declare already on 6 November 1947 that the United States was no longer the only one to possess the secret of atomic bomb production.[19]

The first Soviet nuclear weapons test detonation took place on 29 August 1949. This meant that the nuclear weapons monopoly of the United States had been broken. The policy of strength had suffered a decisive defeat. But the Soviet Union did not yet have nuclear weapons stockpiles.

On 31 January 1950, Truman signed an order obligating the AEC to make every effort to create a "thermonuclear weapon."[20]

While the detonation equivalents in nuclear fission weapons were still counted in the thousands of tons of TNT, they now grew into the Megaton range. On 1 November 1952, the United States, on Elugelab Island, in the Pacific Ocean, for the first time conducted a test with a thermonuclear device (code name "Mike"). The detonation intensity was 5 Mt and it was thus 250 times greater than that of the Hiroshima bomb.[21] This was a pure test detonation which as yet did not permit any direct military use. The explosive as such weighed about 50 t. The gaseous hydrogen isotopes deuterium and tritium were used as nuclear charge during the synthesis phase.

On 28 February 1954, the United States triggered a second test detonation with an intensity of 15 Mt on Bikini Atoll. This was a transportable device.

On 26 March of the same year, another detonation of similar intensity followed on the Marshall Islands. It may be assumed that lithiumdeuteride (LiD) was used in both cases as nuclear charge.[22]

The enormous speed with which nuclear weapons development continued in the Soviet Union is pointed up by the fact that the first test detonation of a multi-phase nuclear weapon became possible already on 12 August 1953.

According to data from the United States AEC, lithiumdeuteride was used either partly or completely in place of the expensive tritium for nuclear synthesis already during this first experimental detonation. This also explains the fact that the explosive itself was transportable. Other "thermonuclear" test detonations followed in September and October 1954.

On 22 November 1955, the Soviet Union conducted the first air burst of a multi-phase nuclear weapon. The weapon was dropped from an aircraft. All prior thermonuclear detonations in the United States and the USSR until then had been ground bursts.

The first such air burst came off successfully in the United States only on 21 May 1956.[23] These facts show that the Soviet Union was in a position simultaneously to work on the problems of using nuclear fission and nuclear synthesis, finding favorable design solutions quickly, and thus, in the case of multi-phase nuclear weapons, arriving at militarily usable devices faster and creating corresponding stockpiles in shorter periods of time than the United States--all this in spite of the vast losses and damage caused by the fascist attack and more unfavorable economic preconditions.

Even the tremendous efforts of the United States during the following years were unable to change anything on the fact that balance of power was always shifting in favor of the Soviet Union also in the field of nuclear weapons.

In 1953-1957, equality was achieved in nuclear weapons development between the Soviet Union and the United States; during the years thereafter, the Soviet Union gained superiority. On top of that we have the fact that the Soviet Union, parallel to the nuclear warheads, also developed the required delivery vehicles. Thus, TASS [Telegraph Agency of the Soviet Union] on 27 August 1957 reported that the first intercontinental missile had been tested in the Soviet Union. On 4 December 1962, Marshal Biryuzov in the army newspaper KRASNAYA ZVEZDA reported that the Soviet Army had warheads of 50-60 Mt for intercontinental missiles. This meant that even the United States itself was no longer invulnerable.

In recent years the United States again and again tried to make its alleged superiority credible in the field of nuclear weapons. To do that, it used above all the loyal monopoly press to propagate ever new variations of "modern nuclear weapons." Here are some examples.

In 1957 came the so-called "clean bomb," that is to say, a nuclear weapon with less radioactivity (energy release exclusively based on nuclear synthesis); it was touted as being particularly "humane" and served as a pretext for the continuation of American nuclear weapons tests.

Starting in 1959, approximately, American voices were again heard, trying to prove in particular that only the United States, on the basis of "its economic strength," was in a position to produce "smaller nuclear weapons" in adequate quantities.

In 1960, the new "miracle weapon" was the "neutron bomb" which was to work primarily through the neutron component of instant nuclear radiation. In contrast to all the noise about the "clean bomb," it was advertised as being particularly effective precisely because it would act upon man above all through nuclear radiation while the blast wave and the flash [light radiation] would be of subordinate significance in terms of their destructive effect. Here is how the situation was described: "A revolutionary novel nuclear secret weapon has been developed by American scientists according to information supplied by former AEC member Murray. Murray at the same time emphatically came out in favor of lifting the atomic test ban which in effect made it impossible for the United States to win a new position of military and political strength. In the opinion of an American nuclear physicist, who does not wish his name to be known, the new weapon could be a 'neutron bomb' which releases lethal rays without causing any property damage."[24]

Starting in 1961, SAC conducted flights with nuclear bombs on board in the direction toward the Soviet Union and the socialist states. Among the four routes regularly flown, three run from the United States via Canada or Alaska or Greenland and the Polar region while the fourth one extends from the United States across the Middle Atlantic all the way to Spain.

In addition to the potential threat to the entire socialist camp, this kind of action is connected with a direct threat to the countries over which those planes fly. Between 1958 and 1968 alone there were 14 incidents involving nuclear bombs as well as various complications in SAC.

On 17 January 1966, a B-52 exploded during such a flight while refuelling in the air over the Spanish village of Palomares. At that time, three multi-phase nuclear bombs fell on farmland and the fourth one dropped 840 m deep into the Mediterranean.

On 21 January 1968, a B-52 crashed at Thule in the northwestern part of Greenland, hitting the permafrost surface; it exploded and the four nuclear bombs, with an intensity of 1 Mt, each, sank to a depth of 250 m.

Even if one keeps in mind that the multiple safeguard systems practically rule out any unintentional nuclear detonation in this kind of crash, there are still enough danger sources left.

For example, the decomposition of the plutonium fuse due to pressure and heat or the corrosion of the bomb casing cause a radioactive contamination of the terrain or the water. But this directly creates the danger of incorporating the alpha-active plutonium.[25]

England was the third country which, on 3 October 1952, conducted a nuclear fission weapons test on the Monte Bello Islands (northwestern part of Australia). The British nuclear weapons project had been launched in the autumn of 1951 under the code name "Tube Alloys Directorate" under the direction of Wallace Akers. Two other tests followed in 1953 at the Woomera Range in the southern Australian desert. The first test detonation involving a thermonuclear device was carried out on 15 May 1957 in the area of Christmas Island in the Pacific Ocean.

France was the fourth country on 13 February 1960 to detonate its first nuclear fission bomb at Reggane in the Sahara Desert. On 24 August 1968, it set off a thermonuclear device on Fangataufa Atoll in the Pacific Ocean.

Table 1.2. Data on the First "A and H Bomb Test Detonations"[26]

Staat	»A-Bombe«	Ort	Bemerkungen	»H-Bombe«	Ort	Bemerkungen
USA	16.07.1945	Alamogordo (New Mexiko)	»Trinity-Test« Pu-239, 10 kt Implosionsprinzip	01.11.1952	Eluglab (Stiller Ozean)	Test »Mike« D,T; 5 Mt nicht transportabel
			Stahlturm (30 m)	28.02.1954	Bikini (Stiller Ozean)	LiD; 15 Mt transportabel
UdSSR	29.08.1949		kt-Bereich Pu-239	12.08.1953		Mt-Bereich LiD transportabel
England	03.10.1952	Monte Bello (Australien)	kt-Bereich	15.05.1957	Christmas-Insel (Stiller Ozean)	Mt-Bereich
Frankreich	13.02.1960	Reggane (Wüste Sahara)	60 ... 70 kt Turm (100 m)	24.08.1968	Fangataufa (Stiller Ozean)	2 Mt
VR China	16.10.1964	Provinz Sinkiang	U-235, 20 kt Turm	17.06.1967	Provinz Sinkiang	3 Mt

Key: 1—Country; 2—Place; 3—Remarks; 4—Implosion principle; 5—Steel tower; 6—Pacific Ocean; 7—Not transportable; 8—Transportable; 9—USSR; 10—Kt range; 11—Mt range; 12—Australia; 13—Christmas Island; 14—France; 15—Sahara Desert; 16—Tower; 17—PRC; 18—Province of Sinkiang.

The PRC was the fifth and, for the time being, last country which on 16 October 1964 announced the first test detonation of a nuclear fission weapon. The test site was in the Province of Sinkiang. A thermonuclear device was exploded at the same site on 17 June 1967.

At this time we must estimate that a series of other imperialist states are working on the manufacture of nuclear weapons, are considering such steps, or are able to do so. Worldwide scientific and technical developments have produced a situation in which today there is practically no more "atomic secret" so that, in the final analysis, only the particular economic strength of a country will decide on the possibility of producing nuclear weapons.

Table 1.2 presents an overview of the first test detonations by the individual countries. In compiling this table and the following one, the problem was that the material available for analysis was not authentic in each case and that conflicting data are available in the literature on various events.

Overall, about 740 nuclear weapons detonations were triggered by the five nuclear powers between 1945 and 1970. We may estimate that this number is too low, rather than too high.

Regardless of this fact, Table 1.3 clearly shows that, even according to Western data, the Soviet Union confined the number of its tests to the militarily possible minimum.

On the basis of available data, we may furthermore estimate that the total equivalent of the detonation energy of all nuclear tests conducted so far is roughly on the order of magnitude of 500-550 Mt TNT.

Of that amount, about 400 Mt were used in about 100 tests in the Mt range in the atmosphere. The remaining 100-150 Mt must be credited to nuclear weapons detonations in the kt range and a few underground detonations in the Mt range. To be able to visualize these orders of magnitude, we may start with the assumption, by way of comparison, that the total intensity of the explosives (bombs, shells, etc.) employed during World War II by all belligerent countries was about 5 Mt.

The tests conducted so far were air, surface, water, and underwater detonations. Here it is particularly difficult to estimate the detonation intensities of underground detonations that were not officially announced. Until the year 1963, the share of underground and underwater detonations out of the total number of tests in the kt range was about 50 percent. Between 1964 and 1970 on the other hand underground detonations alone accounted for more than 90 percent of all tests conducted.

According to Western literature data, the hitherto strongest nuclear weapons detonation with 57 Mt was triggered by the Soviet Union on 30 October 1961 over Novaya Zemlya. The weakest test with a detonation intensity of only 0.0002 took place in Nevada on 30 October 1958. The hitherto highest detonation altitudes would seem to have been selected by the United States during the Argus series in August and September 1958 (three tests at 2 kt, each, at

an altitude of 480 km) and 9 July 1962 with a 1.2-Mt test at an altitude of 320 km over Johnston Island in the Pacific. The hitherto deepest known underground detonation with an intensity of 5 Mt at a depth of 2,000 m was triggered by the United States, in spite of worldwide protests, on 6 November 1971 on the Aleutian island of Amchitka.

Table 1.3. Compilation of Nuclear Weapons Detonations by the Individual Countries, 1945-1970[26]

		1945	1946	1947	1948	1949	1950	1951
	USA	3	2	–	3	–	–	17
	UdSSR	–	–	–	–	1	–	2
1	Insgesamt:	3	2	–	3	1	–	19
		1952	1953	1954	1955	1956	1957	1958
	USA	9	11	6	15	14	28	66
	UdSSR	–	2	1	4	7	13	25
	England	1	2	–	–	6	7	5
1	Insgesamt:	10	15	7	19	27	48	96
		1959	1960	1961	1962	1963	1964	1965
	USA	–	–	8	87	46	29	27
	UdSSR	–	–	30	38	3	5	8
	England	–	–	–	2	–	–	1
2	Frankreich	–	3	1	1	1	1	–
3	VR China	–	–	–	–	–	1	1
1	Insgesamt:	–	3	39	128	50	36	37
		1966	1967	1968	1969	1970	1945-1970	
	USA	9	33	32	27	27	499	
	UdSSR	2	8	7	12	9	177	
	England	–	–	–	–	–	24	
2	Frankreich	5	4	5	–	8	29	
3	VR China	3	2	1	2	1	11	
1	Insgesamt:	19	47	45	41	45	740	

Key: 1--Total; 2--France; 3--PRC; UdSS--USSR.

Figure 1.6. Geographic location of the most important nuclear weapons test sites of the United States, England, France, and the PRC.

Explanation for Figure 1.6

United States test sites: Nevada, U.S.A. (1), New Mexico, U.S.A. (2), Johnston Islands, south of Hawaii, Pacific Ocean (3), Bikini (Island), Marshall Islands, Pacific Ocean (4), Eniwetok (Island), Marshall Islands, Pacific Ocean (4), Amchitka (Island), Aleutians (5).

England's test sites: Woomera, southern Australia (6), Monte Bello (Islands), off the northwest coast of Australia (7), Christmas Island, Gilbert and Ellice Islands, Pacific Ocean (8).

France's test sites: Reggane, Central Sahara (9), Muruoa (Island), French Polynesia, Pacific Ocean (10), Fangataufa (Island), French Polynesia, Pacific Ocean (10).

PRC test sites: Province of Sinkiang, northwestern part of China (11).

Between 1945 and today we have two phases during which there were no nuclear weapons tests or during which these tests were or still are subjected to certain restrictions.

The first relative test suspension period, which was not based on any treaty agreement, lasted from the autumn of 1959 until September 1961. During that span of time, only France conducted nuclear weapons tests.

The second relative period of test suspensions began on 5 August 1963. On that date, the foreign ministers of the Soviet Union, the United States, and Great Britain signed the "Agreement on the Suspension of Nuclear Weapons Tests in the Atmosphere, in Outer Space, and Under Water" in Moscow. This step restricted the increasing "radioactive pollution" of the earth's atmosphere and the ocean water--but it only restricted it because France and the PRC did not sign that agreement. Another important step toward a reduction in international tensions was taken in 1968. After many years of constructive proposals by the Soviet Union and its efforts to achieve visible results in disarmament negotiations,

a proposal, submitted by the Soviet Union, was signed on 18 January 1968; the "Draft for a Treaty on the Nontransfer of Nuclear Weapons" was signed in Geneva by the 18-member disarmament committee of the UN.

The United States had submitted an identical treaty draft. On that basis, the 22nd UN General Assembly with an overwhelming majority on 12 June 1968 passed the nuclear weapons ban treaty which finally on 5 March 1970 entered into force after having been signed by more than a hundred countries, including of course the GDR. This created obligations which were binding under international law, obligations to refrain from any further dissemination of nuclear weapons and to stop the efforts of non-nuclear countries to gain access to nuclear weapons in any form whatsoever.

Negotiations then began in 1969 between the Soviet Union and the United States concerning the use of nuclear detonations for peaceful purposes; these negotiations are still going on as we prepare this chapter (August 1971).

The past history of nuclear weapons sketched here briefly, also confirms the observation of the International Conference of the Communist and Worker Parties of August 1969 in Moscow: "In view of the existing international balance of power, the nuclear weapons potential of the Soviet Union, and the possible consequences of a nuclear missile war, it is becoming increasingly difficult and dangerous for United States imperialism to bank on unleashing a new world war. Under these conditions, ruling American circles place special emphasis on local wars without abandoning the preparations for a world war. But the contrast between the policy of strength pursued by imperialism and its real possibilities is emerging ever more crassly."[27]

Review Questions

1.6. Into what fundamental stages can the past history of nuclear weapons be broken down?

1.7. Explain why the rapid development of Soviet nuclear weapons "was a matter of life and death for the defense of the Soviet Union."

1.8. What are the causes for the fact that the Soviet Union was able quickly to break the American nuclear weapons monopoly and then to achieve and maintain a lead in the development of nuclear missiles?

1.9. What international and military significance is attached to the Agreement on the Suspension of Nuclear Weapons Tests in the Atmosphere, in Outer Space, and Under Water, dated 5 August 1963, and the entry into force of the Nuclear Nonproliferation Treaty, dated 5 March 1970?

1.10. What is the connection between the need for constantly increasing the combat readiness of the NVA [National People's Army] and the struggle of the socialist countries, headed by the Soviet Union, for disarmament and a general ban on the use of nuclear weapons and other mass annihilation weapons?

1.3. Structure of Nuclear Fission Weapons

1.3.1. Nuclear Fission as Basis of Energy Release

1.3.1.1. Mass Defect and Nuclear Binding Energy[28]

Three types of elementary particles are involved in the immediate build-up of the atoms: Electrons, protons, and neutrons.

The atom itself consists of a relatively loose envelope of electrons and a very small nucleus with an extraordinarily high mass and charge density. The outside diameter of an atom is on the order of magnitude of 10^{-10} m, that of the nucleus is only 10^{-15} m. More than 99.9 percent of the total mass [weight] of an atom are concentrated in the nucleus. This means that the nucleus has a mass density of about 10^{17} kg m^{-3}.

Concerning the problems of nuclear energy release, we are only interested in the atomic nucleus. The energy amounts which can be released by changes in the nuclear structure can be 10^6 times higher than in chemical reactions.

In keeping with the theory of relativity, a particle also still has energy if its velocity is zero. This energy is called rest energy. The following relation then applies:

$$E = m \cdot c^2 \qquad (1.1)$$

It expresses the equivalence of energy and rest mass of a particle and, during the release of nuclear energy, supplies the connection between nuclear binding energy and mass defect. If, for example, we mathematically determine, from the individual masses, the mass of a helium atom (^4_2He; $2e^-$) on the basis of the values in Table 1.4 with the help of the following formula

$$m_A = Z \cdot m_p + N \cdot m_n + Z \cdot m_e \qquad (1.2)$$

Then, using the relative atomic weights, we get a value of $m_{He} = 4.0329$ ME. Compared to the real atomic weight of helium (m = 4.0026 ME), this value turns out to be 0.0303 ME too high.

Table 1.4. Brief Characteristics of Elementary Particles: Electron, Proton, and Neutron

1	Elementarteilchen	Elektron	Proton	Neutron
	Symbol	e^-	p	n
2	Ruhemasse, absolute kg	$9{,}1091 \cdot 10^{-31}$	$1{,}6725 \cdot 10^{-27}$	$1{,}6748 \cdot 10^{-27}$
3	Ruhemasse, relative ME[1]	0,000549	1,00727	1,00865
4	Ruhemasse, äquv. MeV/c^2	0,5110	938,3	939,5
5	Elementarladung	−1	+1	0
6	mittlere freie Lebensdauer s	stabil 7	stabil 7	$1{,}0 \cdot 10^3$

Key: 1--Elementary particle; 2--Rest mass, absolute; 3--Rest mass, relative; 4--Rest mass, equivalent; 5--Elementary charge; 6--Average free lifetime; 7--Stable; (1) The relative atomic mass (rest mass) must not be confused with the mass number (mass number = proton number + neutron number); A = Z + N). Since 1961, the atomic mass unit has been defined as follows: 1 ME = 1/12 atomic mass of $^{12}_{6}C$ = $1.66043 \cdot 10^{-27}$ kg. The relative atomic mass accordingly is the ratio between the atomic mass of the corresponding atom (particle) and the atomic mass unit.

By way of explanation we might say that, during the formation of an atomic nucleus from free nucleons (protons and neutrons)--there develops a mass defect in whose place there comes an energy quantity which is equivalent according to Formula 1.1.

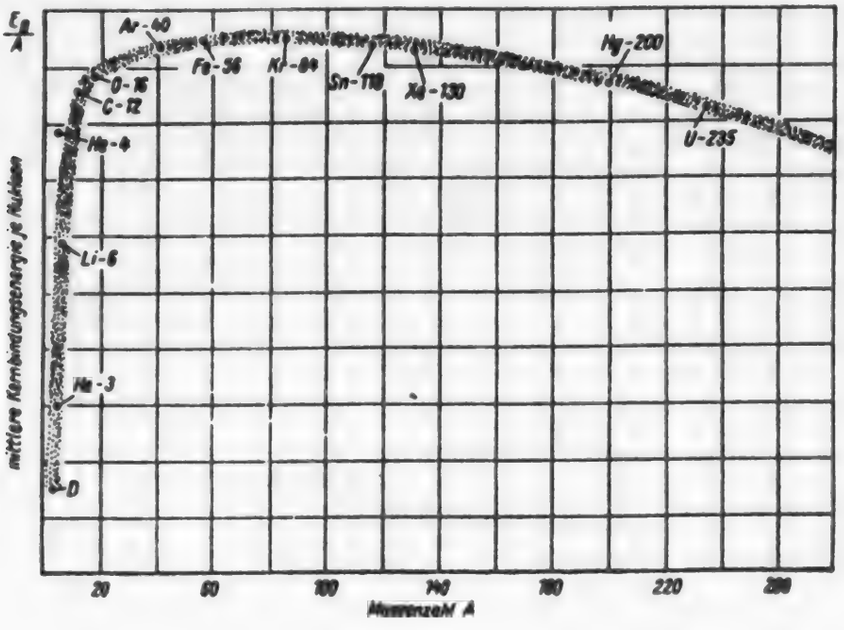
If we wanted to reverse this process, this energy would precisely once again have to be used for the separation of the nucleons. Looking at it this way nuclear energy is, by virtue of its essence, nuclear binding energy. Or, in other words, the more firmly a nucleon is bound to a nucleus as a result of a nuclear reaction, the greater will be the attendant mass defect and thus the released equivalent energy quantity.

The reciprocal processes between atomic nuclei of varying structure or between those with different nuclear-active particles is considerably more complicated than the above example of the buildup of an atom or atomic nucleus from elementary particles. Such nuclear reactions can reveal both a positive and a negative energy balance. Basically, nuclear energy is released only if the mass of the nuclei or nuclear particles participating in the reaction meet the following inequality:

$$\Sigma m_{\text{original [parent] nuclei}} > \Sigma m_{\text{product}} \qquad (1.3)$$

We get initial conclusions as to the anticipated energy toning of a nuclear reaction if we illustrate the nuclear binding energy per nucleon as a function of the mass number; that is to say, in other words, if we divide the binding energy of any desired nucleus by the number of nucleons forming that nucleus.

In this case we can recognize that, up to a mass number of A = 60, the average nuclear binding energy per nucleon grows rapidly in terms of tendency and then again slowly decreases in the direction toward the heavy nuclei. Thus the average binding energy per nucleon is about 7 MeV for helium, 9 MeV (maximum) for iron, and 7.5 MeV for uranium; for the total spectrum of atomic nuclei, the value on the average is 8 Mev; this corresponds to a mass defect of 0.0089 ME. Nevertheless, especially in some light nuclei, there are considerable deviations from these average values. We can furthermore observe that the binding energy per nucleon for nuclei with an even mass number is greater than for the neighboring nuclei with an uneven mass number.



1

2

Figure 1.7. Average nuclear binding energy per nucleon as function of mass number A[29]. Key: 1--Average nuclear binding energy per nucleon; 2--Mass number A.

By way of summary, from what we have said here so far, we can derive two possibilities of nuclear energy procurement which were formulated already in Section 1.1., that is, the buildup of heavy nuclei from light nuclei and the fission of heavy nuclei into medium ones.

To continue our look at energy release based on nuclear fission (nuclear synthesis) it is not enough to illustrate the nuclear binding energy simply as a function of the mass number A because the latter after all consists of Z and N. Concerning the stability of a nucleus, the breakdown according to even or

odd proton and neutron numbers ((g, g)-, (g, u)-, (u, g)-, (u, u)- nuclei) provides further insight. It thus turns out that, in nature, nuclei of type (g, g) predominate (164 stable nuclides) while only four stable nuclides are known of nucleus type (u, u). In general we can say that the stability of the individual nucleus types decreases in the sequence mentioned above.

The stability of atomic nuclei is essentially determined by the number and the mixing ratio of protons and neutrons. For stable nuclei, we have $N = Z$, whereas for heavy nuclei we must have $N > Z$. Starting $Z \geq 84$ (Polonium), we only have unstable nuclides.

In the atomic nuclei which are made up of protons (positive elementary charge) and neutrons (no electrical charge), there must be different forces present which, in their totality, determine its stability or instability. In simplified form, this interconnection can be boiled down to the opposing action of the nuclear forces and the Coulomb forces.

Experience shows that there are strong binding forces also between the protons or neutrons among each other and between protons and neutrons as such. The magnitude of the binding forces decreases very rapidly as the distance increases; their practical range does not exceed $2 \cdot 10^{-15}$ m. These nuclear forces cause the formation of the nucleus from the nucleons. The nuclear forces act only between neighboring nucleons. This shows us that the "surface nucleons," which after all do not have any external neighbors, are bound more weakly than those deep in the nucleus. This assumption furthermore yields a certain surface tension and the explanation for the fact that most nuclei have a roughly spherical shape ("dr plet model" or the atomic nucleus).

The nature of nuclear forces is still not fully understood. According to H. Yukawa, nuclear forces--similar to chemical binding forces--are considered exchange forces between the nucleons. The π-mesons or pions are considered as carriers of the nuclear force field. They can be exchanged between the nucleons.

The Coulomb forces, which work against the nuclear forces, result from the repelling effect of protons with the same charge. In comparison to them, they have a considerably greater range. Their magnitude decreases with the square of the distance between the protons. This is why each of the Z-protons acts upon the other (Z-1) protons.

While the nuclear forces increase only in proportion to Z, the Coulomb forces increase at Z^2. Because of the change in the ratio between protons and neutrons from 1:1 to about 1: 1.6--a change extending from the light to the heavy atomic nuclei--there is an increase in the average distance between the protons; but that cannot prevent the fact that, in the end, in case of very high nuclear charge numbers, the Coulomb forces will prevail which means that the nucleus becomes unstable. An atomic nucleus thus is stable so long as the following condition is met:

$$\Sigma F_{\text{nuclear forces}} > \Sigma F_{\text{Coulomb forces}} \qquad (1.4)$$

According to Bohr, the folowing inequality applies here:

$$\frac{Z^2}{A} < 45 \quad \text{or} \quad \frac{Z^2}{Z+N} < 45 \tag{1.5}$$

1.3.1.2. Basic Condition for Nuclear Fission

Nuclear fission reactions can basically be triggered in a whole series of nucleus types. But only a certain number of heavy nuclei is suitable for use as fission materials (nuclear explosives). As far as we know now, for nuclear fission weapons, that would be the nuclides U-233, U-235, Pu-239, and possibly also Cf-249 and Cf-251. The nuclides U-238 and (Th-232) can furthermore be considered for use in multi-phase nuclear weapons.

The nuclei of these radionuclides are subjected to spontaneous nucleus decay or alpha decay. Compared to the half-life for the spontaneous nuclear decay ($T_s = 1.8 \cdot 10^{17}$ a for U-235) with those of alpha decay ($T_\alpha = 7.1 \cdot 10^8$ a for U-235) however shows that spontaneous fission is only very rare. From this we can also without further consideration draw the conclusion that a certain activation energy must be used in order to bring about forced nuclear fission. Its magnitude for nuclei with a mass number of A ~ 230 is less than 10 MeV.

The required activation energy can be supplied to the nucleus to be split by means of photons or due to the impact of particles (kinetic energy) and/or by their absorption (formation of an intermediate nucleus--binding energy). In the case of nuclear fission weapons, the neutrons are the sources of this activation energy.

The basic condition for nuclear fission in nuclear weapons consists in the fact that the sum of the binding energy E_B of the neutron absorbed in the intermediate nucleus and its kinetic energy E_{kin} is equal to or greater than the required activation energy E_w for the nuclide used as nuclear charge.

The following applies as a prerequisite for nuclear fission by means of neutrons:

$$E_{B(n)} + E_{kin(n)} \geq E_w \tag{1.6}$$

Table 1.5 shows the activation energies for the most important nuclear explosives. We can see that, in the case of U-235 and Pu-239, the bonding energy of the neutron corresponds to the necessary activation energy or exceeds it. Something similar applies to U-233 which is not listed in the table. This is why these nuclides can already be split by thermal neutrons. (Thermal neutrons at 25° C have an average energy of $\bar{E}_n = 0.025$ MeV, at an average velocity of $\bar{v} = 2.2 \cdot 10^3$ m s^{-1}.) On the other hand, fast neutrons with an energy of $E_n \geq 1.5$ MeV are necessary for splitting U-238 (Th-232).

Table 1.5. Activation Energy E_w (Neutrons) in Terms of MeV for Some Heavy Nuclei[30]

Original nucleus	U-235	U-238	Pu-239
Intermediate nucleus	U-236	U-239	Pu-240
Activation energy	6.5	7.0	5.1
Neutron's binding energy	6.8	5.5	5.1
Neutron's kinetic energy	0	1.5	0

This difference exerts decisive influence on the possibilities of using both of these groups of nuclear explosives. We will go into greater detail on that later on.

With the help of the droplet model for the atomic nucleus it is possible clearly to illustrate the nuclear fission process. The supply of activation energy--which is connected with the absorption of the neutron and the formation of the intermediate nucleus--excites the fissile nucleus into pulsating oscillations. As a result of these oscillations, the previously spherical nucleus is deformed and it assumes a longitudinal, dumbbell-like shape. Two, spatially separated positive charging foci now begin to form, the Coulomb forces gain the upper hand, and finally lead to the splitting of the nucleus into two fragments (nuclear fragments). At the same time, two or three neutrons are released during this process. This is connected with the release of an energy amount that is equivalent to the developing mass defect and whose carriers [sources] are the nuclear fragments which move away from each other at fast speed, the neutrons, and the immediately emitted nuclear radiation (see Section 1.3.4.).

To conclude these elementary considerations, we might note that, even under the conditions given, not every absorption of a neutron need necessarily lead to nuclear fission. Instead, nuclear fission, like any other nuclear reaction, takes place only with a certain probability. Thus, we can match nuclear fission with a certain "action profile" which specifically depends on the nuclear structure and the energy of the neutrons.

If we look at the example illustrated in Figure 1.8, we find the following reaction probabilities:

During the absorption of thermal neutrons by U-235 nuclei, the probability of nuclear fission is 85 percent; in 13 percent of the cases, we get, on the average, neutron capture with the emission of a γ-quantum ((n, γ)-reaction) and in 2 percent of the cases we get elastic scatter ((n, n')-reaction).

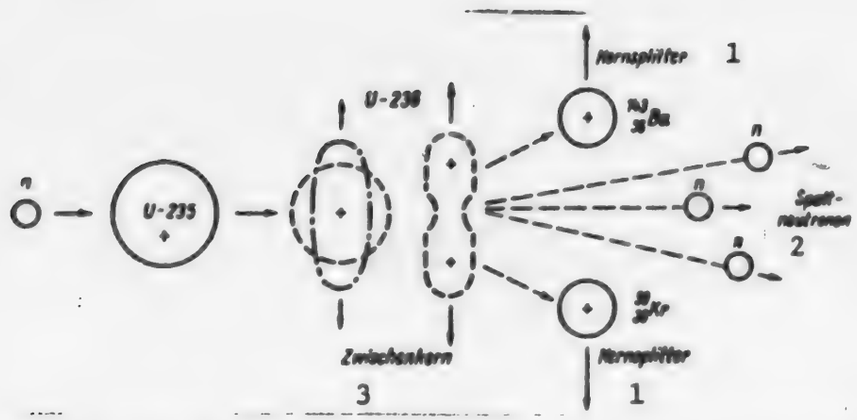


Figure 1.8. Basic diagram illustrating forces nuclear fission through neutron bombardment. Key: 1--Nuclear fragments; 2--Fission neutrons; 3--Intermediate [compound] nucleus.

1.3.1.3. Chain Reaction in Nuclear Explosive

The fission of the nuclear explosives mentioned is accompanied by four common characteristics:

For each nucleus split, we get an energy amount on the order of magnitude of about 200 MeV;

Two or three neutrons per fission event are released;

At the moment of fission, an average of 2 gamma quantums are emitted;

The nuclear fragments of the uranium or plutonium nucleus--the fission products--developing as a result of fission are radioactive.

The characteristic mentioned in second place--according to which secondary neutrons develop during nuclear fission--is particularly important. If the binding energy of these fission neutrons is enough in order, in turn, to bring about more nuclear fission, then a fission process, which has been initiated, can under certain conditions continue by itself and lead to a so-called chain reaction. This as we know applies to the nuclides U-233, U-235, and Pu-239.

The possibility of more nuclear fission due to secondary fission neutrons however does not yet lead to the development of such a chain reaction whose result is the release of nuclear energy through a detonation. For that, a series of other conditions must be met, that is to say, first of all, the chain reaction must continue via a number of fission cycles that will release enough energy and, besides, energy release must take place within a sufficiently short time interval.

The term "chain reaction" in the case of nuclear weapons means a series of exoergenic nuclear reactions which, after external initiation, will continue by themselves and which--due to the number of fission neutrons that keeps growing from generation to generation, from fission cycle to fission cycle--will

encompass more and more nuclei, will grow like an avalanche, and will thus release large quantities of energy within fractions of seconds in the form of a detonation.

As a basic prerequisite for the detonation-like release of nuclear energy, it emerges from the definition given that the number of fission neutrons must grow from generation to generation; that is to say, that the neutron multiplication factor k must be greater than unity.

The neutron multiplication factor k is defined as the quotient of the i/i-1 neutron generation.

A system, for which $k < 1$ applies, is termed subcritical. A reaction initiated from the outside will quickly die down again. When $k = 1$, a system is critical. The reaction takes place at steady speed and the energy release takes place in proportion to the reaction time (reactor).

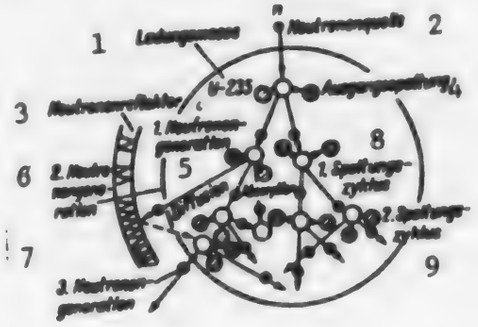


Figure 1.9. Basic diagram illustrating the course of the chain reaction in nuclear fission weapons. Key: 1—Charge mass; 2—Neutron source; 3—Neutron reflector; 4—Initial fission; 5—1st neutron generation; 6—2nd neutron generation; 7—3rd neutron generation; 8—1st fission cycle; 9—2nd fission cycle.

At the moment of ignition, $k > 1$ applies to the nuclear weapon.. It must then be considered a supercritical system.

$$k = \frac{i}{i-1} > 1 \qquad (1.7)$$

Under specific conditions, the magnitude of the multiplication factor k depends on the number of neutrons released per fission event, the ratio between the nuclear fission cross-section and the cross-section for other processes not leading to the release of new neutrons, the type, size, and shape of the particular fission material, as well as some other marginal conditions.

If all of the neutrons released during nuclear fission were to cause further fission, then the neutron multiplication factor could attain a maximum value of about $k = 2.5$. This value however cannot be achieved in nuclear weapons. The

most important reasons for this are that a part of the neutrons is diffused out of the nuclear fission zone while another part is absorbed by the fission product, the admixtures, etc.

Basically we must observe that the course of a chain reaction is always tied to a minimum quantity of nuclear explosives.

To bring about a chain reaction when $k > 1$, we need a certain quantity of fission material. This minimum quantity is called the critical mass.

The critical mass is not a fixed absolute magnitude. Instead, it depends both on the nuclear-physics parameters of the particular nuclear explosive and on the design and structure of the nuclear weapon itself. If we start with a spherical charge arrangement, then the size of the critical mass is determined by the effect cross-section, the neutron multiplication factor, and the average free path length of the neutrons. The action cross-section however depends on the velocity (energy) of the fission neutrons. The free path length of the neutrons again is determined by the nuclear fission cross-section and the number of fissile nuclei per charge mass volume unit. This is why the diameter of the nuclear charge in the supercritical state must be considerably larger than the average free path length of the neutron. Further comments on this problem complex can be found in the following chapter.

1.3.2. Basic Elements of Nuclear Fission Weapons

The basic elements of each nuclear fission weapon are the nuclear charge, the detonation device, and the casing.

Without going into detail, we will explain its essential structure and basic function below.

1.3.2.1. Nuclear Charge

The most important characteristic magnitudes for the nuclear charge are the nuclear explosive used, the charge mass, and the charge volume. The tables below present some values in this connection.

Table 1.6. Brief Description of Nuclear Explosives

1	Nuklid	$^{233}_{92}U$	$^{235}_{92}U$	$^{239}_{94}Pu$
2	Kernmasse, absolute kg	$3{,}8694 \cdot 10^{-25}$	$3{,}9027 \cdot 10^{-25}$	$3{,}9693 \cdot 10^{-25}$
3	Kernmasse, relative ME	233,03784	235,04232	239,05033
4	kritische Masse kg[1])	7,5	22,8	5,6
5	Spaltneutronen je Kern	2,5	2,4	2,9
6	Dichte g cm^{-3}	18,7	19,0	19,6
7	T, Alphazerfall a	$1{,}6 \cdot 10^{5}$	$7{,}1 \cdot 10^{8}$	$2{,}4 \cdot 10^{4}$
8	T, spontane Spaltung a	$3{,}0 \cdot 10^{17}$	$1{,}8 \cdot 10^{17}$	$5{,}5 \cdot 10^{15}$
9	rel. Häufigkeit des Isotops bzw. Brutstoff	Th-232[2])	0,71 %	U-238[3])

Key: 1--Nuclide; 2--Nuclear mass, absolute; 3--Nuclear mass, relative; 4--Critical mass; 5--Fission neutrons per nucleus; 6--Density; 7--T, alpha decay; 8--T, spontaneous fission; 9--Relative frequency of isotope or breeder substance.

(1) The data pertain to a system made up of metallic U-233, U-235, or Pu-239 with a standard water reflector. For nuclear fission weapons, the values are considerably lower.

(2) The production of U-233 takes place in breeder reactors from Th-232 according to the following scheme:

$$^{232}_{90}Th\,(n,\gamma)\,^{233}_{90}Th \xrightarrow[\beta^-]{23{,}5\ min} {}^{233}_{91}Pa \xrightarrow[\beta^-]{27{,}4\ d} {}^{233}_{92}U$$

(3) The production of Th-239 from U-238 is based on the following scheme:

$$^{238}_{92}U\,(n,\gamma)\,^{239}_{92}U \xrightarrow[\beta^-]{2{,}3\ d} {}^{239}_{93}Np \xrightarrow[\beta^-]{23\ min} {}^{239}_{94}Pu$$

The detonation energy of 1 kg TNT corresponds roughly to an energy amount of 1,000 kcal. If we therefore insert q in terms of kt in the following expression for the detonation equivalent of a nuclear fission weapon, then we get the following for the total energy released as a function of the detonation intensity:

$$E_{ges} = 10^{6} \cdot q \quad \text{kcal} \qquad (1.8)$$

Considering the corresponding conversion factors for the energy units, it therefore follows furthermore that:

$$E_{Det} = 4{,}187 \cdot 10^{19} \cdot q \quad \text{erg} \tag{1.9}$$

and

$$E_{Det} = 2{,}614 \cdot 10^{33} \cdot q \quad \text{MeV} \tag{1.10}$$

Assuming that an energy amount of 200 MeV is released per nucleus split, we can compute, from the numerical value Equation 1.10, the number of nuclear fission acts z necessary to release the detonation intensity q as follows:

$$z = \frac{E_{Det}}{E_{sp}} = \frac{2{,}614 \cdot 10^{33} \cdot q}{200}$$

$$z = 1{,}307 \cdot 10^{31} \cdot q \text{ nuclei.} \tag{1.11}$$

By inserting the Avogadro constant N_A into this equation ($N_A = 6.02252 \cdot 10^{26}$ $1/(A\ kg)$)[31], it follows, for the size of the necessary charge mass Q' in kg, if the minor differences in the sizes of the kg atoms A kg of U-233, U-235, or Pu-239 are neglected, that:

$$Q' = \frac{z}{N_A} = \frac{1{,}307 \cdot 10^{33} \cdot q}{\frac{6{,}023 \cdot 10^{26}}{235}} = \frac{1{,}307 \cdot 10^{33} \cdot q \cdot 235}{6{,}023 \cdot 10^{26}}$$

$$Q' \approx 0{,}05 \cdot q \quad \text{kg} \tag{1.12}$$

The complete fission of the nuclei of about 500 g of the particular nuclear explosive is thus necessary to release the detonation energy of 1 kt TNT.

Assuming that the nuclear fission of the charge mass of a nuclear weapon always takes place only at a certain efficiency η, the practical mass Q of the nuclear charge must always be considerably larger than Q'. The following then applies as a function of η:

$$Q \approx \frac{0{,}05 \cdot q}{\eta} \quad \text{kg} \tag{1.12}$$

From this it follows for the magnitude of the particular charge volume V_L that:

$$V_L = \frac{Q}{\varrho} \cdot 10^3 \quad \text{cm}^3 \qquad \left|\frac{Q}{\text{kg}}\right| \left|\frac{\varrho}{\text{g cm}^{-3}}\right| \tag{1.13}$$

The values for the density ρ can be seen in Table 1.6.

Regardless of the fact that the size of the nuclear charge of a nuclear fission weapon must correspond to the particular detonation intensity, it must in every

case be greater than the critical mass of the nuclear explosive used. A detonation is impossible under other conditions.

Table 1.7. Reference Values for Important Characteristic Magnitudes of Nuclear Fission Weapons(1)

1 Detonationsstärke	5 kt	10 kt	20 kt	50 kt	100 kt
q/kcal	$5 \cdot 10^9$	10^{10}	$2 \cdot 10^{10}$	$3 \cdot 10^{10}$	10^{11}
q/MeV	$1{,}3 \cdot 10^{26}$	$2{,}6 \cdot 10^{26}$	$5{,}2 \cdot 10^{26}$	$1{,}3 \cdot 10^{27}$	$2{,}6 \cdot 10^{27}$
Q/kg	1,25	2,5	5,0	12,5	25
V_L/cm³	65	130	260	650	1300
r_L/cm	2,5	3,1	4,0	5,4	6,8

Key: 1—Detonation intensity; (1) The data in this table were calculated with the help of the formulas given above, assuming an efficiency of $\eta = 0.2$ of nuclear fission. The value r_L in the last line gives us the theoretical radius of the supercritical charge arrangement.

On the basis of the nuclear physics considerations presented in Section 1.3.1.3 concerning the critical mass we can say by way of generalization that its particular specific size depends on the following:

The type of nuclear explosive,

The shape of the nuclear charge,

The density of the nuclear explosive,

Its purity, as well as,

The construction of the detonation mechanism and the casing.

Other things being equal, the smallest critical mass undoubtedly is attained through a spherical arrangement of the fission material because we then get the best ratio between the volume and the surface of the nuclear charge.

The larger the surface of the active zone in relation to the charge mass, the bigger will be the neutron losses due to diffusion. If therefore the charge volume in terms of its shape deviates heavily from that of a sphere, then the size of the critical mass increases greatly and the neutron losses finally become so heavy that, regardless of the quantity of available nuclear explosive, a detonation becomes impossible. If we have a cylindrical nuclear charge of Pu-239, that, for example, will be the case if the radius of the cylinder is smaller than 2.15 cm (prerequisites same as in Table 1.6).[32] In the combination of subcritical charge parts to make up a supercritical overall system, the ratio between the volume and the surface of the nuclear charge is also changed

necessarily. For example, if, in a certain design of a nuclear fission weapon, we have 10 kg U-235 in the shape of two separate spheres, then their surface is about 240 cm^2, each; after their combination, the total surface on the other hand is only about 310 cm^2.

Changes in the density of the nuclear explosive likewise lead to an immediate change in the overall system's critical parameters. The book entitled "Kerndetonationen" [Nuclear Detonations] already points out that, in the nuclear fission bomb dropped on Nagasaki, by the United States, the critical mass was brought about by means of an implosion.[33] Here, a thin-walled hollow sphere made of Pu-239 was reportedly surrounded by an explosive mantle whose detonation energy upon ignition brought about the supercritical state due to the deformation and compression of the plutonium charge.

Assuming that the density of the nuclear charge and the density of the reflector change in proportion--the function of the neutron reflector will be covered later on--we can say that an increase in the density by the factor a brings about a reduction of the linear dimensions of the critical mass by $1/a$, of the corresponding volume by $1/a^3$, and of the critical mass itself by $1/a^2$.

In other words, this means that the magnitude of the critical mass is inversely proportional to the square of the density. At a pressure of 1 million kp cm^{-2}, the density of the nuclear charge would thus be doubled while the size of the critical mass would still be 1/4 of the initial value.

The purity of a nuclear explosive also exerts essential influence on the magnitude of the critical mass. Here, the particular share of foreign atoms depends especially on the specific production methods (separation methods) used for the fission materials and this must also be considered from economic viewpoints.

For example, a nuclear charge of U-235 will always contain a certain percentage of U-238. U-238 however can be considered an absorber for thermal neutrons. Depending upon the share of foreign isotopes, the fission neutrons thus are subjected either to fission capture or to radiation capture (n, γ). These absorbed neutrons do not participate in the further chain reaction. This causes a deterioration in the neutron multiplication factor and the size of the required critical mass will necessarily increase.

The situation is similar in the case of U-233 and Pu-239. The fission products as well as other construction materials used in the nuclear weapon can also act as neutron absorbers. The problem complex of the neutron reflector and its decisive significance to the size of the critical mass and the efficiency of nuclear explosive utilization will be discussed in connection with the description of the function of the casing of a nuclear fission weapon in Section 1.3.2.3. At this point we might merely remark that, in the case of nuclear fission weapons, it is possible, due to a corresponding construction of the actual reaction compartment, again to throw a part of the neutrons coming out of the active zone back into it and thus to influence the neutron multiplication factor.

1.3.2.2. Detonation Device

The detonation device of a nuclear weapon comprises the ignition mechanism, including the safety system, devices for the fast materialization of the supercritical charge arrangement, as well as additional elements which are necessary for the materialization of the chain reaction and (as a rule) for the maximum utilization of the nuclear charge; in other words, a high efficiency.

The ignition process essentially contains the removal of the last safety device after separation from the delivery means or, upon reaching the target area, the ignition of the initial explosive, the combination of the individual charge parts or the production, elsewhere, of the supercritical mass and the triggering of the chain reaction. Ignition, for example, can be triggered by impact fuses, time fuses, air-pressure fuses (built-in barometer), proximity fuses (radar fuses), or also influence fuses (using the heat radiation or magnetic field influencing of the target). Until the moment of ignition, the nuclear charge is in the subcritical state and is secured several times over and independently of the other components against unintentional detonation.

Considering the mentioned factors which determine or essentially influence the size of the critical mass in a specific charge arrangement, we get several ways to bring about the supercritical state of the nuclear charge and thus to trigger the internal detonation process.

The first basic way consists in the fact that the total charge is so broken down into charge components and placed in the weapon that the mass of each component charge is smaller than the critical mass of the nuclear explosive. But this means that the number of necessary component charges keeps growing as the detonation intensity increases. This cannot be done in an unlimited fashion for certain reasons. If, for example, the size of the critical charge for U-235 increases to about 6 kg (with reflector), then it would be necessary to subdivide the nuclear charge of a nuclear fission weapon with a detonation intensity of q = 100 kt into more than four parts. The biggest difficulty now obviously would not be this subdivision process but rather the simultaneous combination--coordinated to 1/1,000,000 sec, of the individual charge parts to make up the supercritical overall arrangement. If there is even the slightest delay in a charge part, this produces severe effects on the entire course of the detonation and the magnitude of the released detonation energy. This is why one may assume that this principle is used only in conjunction with small detonation intensities.

The second basic way consists in the fact that the supercritical charge mass is brought about as a result of an implosion. In this case, the entire nuclear charge is placed in the weapon in a compact fashion so that there are no mobile individual charge parts. The overall charge nevertheless is in the subcritical state and this is due to the fact that the nuclear explosive is arranged in the shape of a thin-walled sphere or is present as a loose, highly porous material. The nuclear charge itself is surrounded by a neutron reflector which, in turn, again is surrounded all over by the initial explosive. At the moment of ignition, the reflector and the nuclear charge are compressed extremely powerfully and as a result of that the total system becomes supercritical and the nuclear weapon explodes.

In addition to these possibilities of switching the nuclear weapon from the subcritical to the supercritical state mentioned here, others are conceivable which however are of minor significance in understanding the overall problem complex and which therefore will not be further described here.

A decisive prerequisite for a high degree of nuclear explosive utilization among other things consists in the fact that, at the moment of ignition, the supercritical charge state is in fact brought about instantly and that the process of energy release takes place in the shortest possible time interval.

This simply springs from the fact that the weapon is broken down very quickly as a result of the detonation although about 90 percent of the total detonation energy comes only from the last fission cycle of the chain reaction.

Table 1.8 presents an overview of the number of fission cycles n, the total duration of the course of the chain reaction t, as well as the time span t_1 during which about 90 percent of the detonation energy are released. The data in the table were calculated for a multiplication factor of k = 2 and an average time duration of 10^{-8} sec between two fission events.

Table 1.8. Reference Values to Describe the Course of the Chain Reaction

1 Detonationsstärke	5 kt	10 kt	20 kt	50 kt	100 kt
n	79	80	81	83	84
t/s	$7{,}9 \cdot 10^{-7}$	$8{,}0 \cdot 10^{-7}$	$8{,}1 \cdot 10^{-7}$	$8{,}3 \cdot 10^{-7}$	$8{,}4 \cdot 10^{-7}$
t_1/s	$5{,}1 \cdot 10^{-8}$	$6{,}5 \cdot 10^{-8}$	$8{,}1 \cdot 10^{-8}$	$1{,}1 \cdot 10^{-7}$	$1{,}4 \cdot 10^{-7}$

1. Key: 1—Detonation intensity.

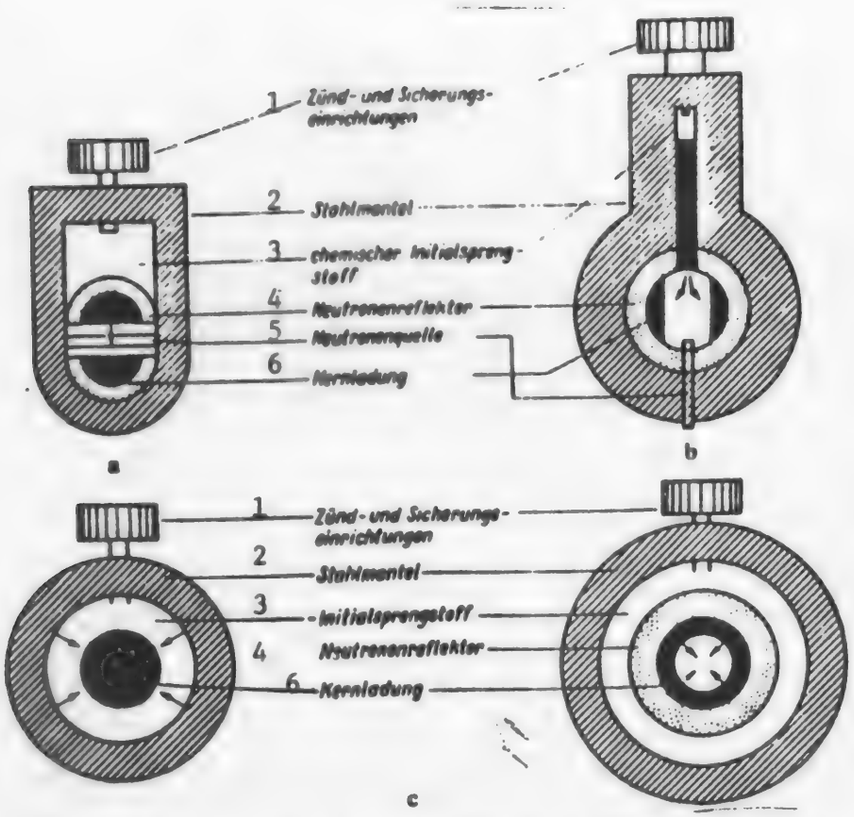


Figure 1.10. Greatly simplified illustration of the structure of nuclear fission weapons. a--Combination of two charge parts; b--Combination and deformation of charge parts; c--Implosion. Key: 1--Ignition and safety mechanisms; 2--Steel casing; 3--Chemical initial explosive; 4--Neutron reflector; 5--Neutron source; 6--Neutron charge.

Regardless of the relative information provided by these figures, they do make it clear how small the differences for n and t are for the individual detonation intensities. This is why they have an extraordinarily powerful effect on the released summary detonation energy already in case of the slightest time shifts in the course of the chain reaction. During each nuclear weapons detonation we would therefore expect a more or less strong deviation from the standard value given for the detonation intensity.

The smaller the real value of the neutron multiplication factor k is, the greater will be the required reaction time to release the energy of a certain detonation intensity k and the longer will the charge mass of the nuclear weapon have to be held together. In comparison to the values given in the tables we thus get the following: for q = 100 kt and k = 1.2; for n = 310, $t = 3.1 \cdot 10^{-6}$ sec, and $t_1 = 5.2 \cdot 10^{-7}$ sec.

In general, the total nuclear reaction time is as follows:

$$t = n^* t_m \text{ s} \qquad (1.14)$$

n = Number of fission cycles taking place
t_m = Average time between two fissions ($t_m = 10^{-8}$ s)

To produce a detonation energy of q kt, as we showed, it is necessary to split $z = 1.307 \times 10^{23} \cdot q$ nuclei.

The following furthermore applies in case of a neutron multiplication factor k = 2 and an initial value of $a_1 = 1$ for the chain reaction (that is to say, no separate neutron source, see below):

$$z = \frac{k^n - 1}{k - 1} = 2^n - 1 \approx 2^n \qquad (1.15)$$

It follows from this that:

$$z = 2^n = 1{,}307 \cdot 10^{23} \cdot q$$

and dissolving for n, we get the corresponding number of fission cycles as follows:

$$n = 76{,}81 + 3{,}32 \lg q \qquad (1.16)$$

According to Formula 1.14 we get the chain reaction time as follows from this:

$$t = (76{,}81 + 3{,}32 \lg q) \cdot 10^{-8}\ \text{s} \qquad (1.17)$$

Similar considerations give us approximately the following relationship for the determination of the t_1 value:

$$t_1 \approx 3{,}0 \cdot 10^{-8} \cdot q^{1/3}\ \text{s} \qquad (1.18)$$

An essential element in the detonation device of nuclear fission weapons consists of the neutron sources. They are inserted into the nuclear weapon prior to employment and can have two basic functions.

First of all, they are intended to trigger the chain reaction at the moment of ignition in an instantaneous fashion; besides, they can increase the efficiency of nuclear explosive utilization. In the last case, their purpose is to reduce the number of fission cycles required for the release of a certain detonation energy. To perform this function, the neutron sources used, however, must be highly active.

If, for example, we start with a neutron source with a yield of 10^{10} neutrons per second, then the total chain reaction time when q = 100 kt and k = 2 will be reduced by about $\Delta t = 8 \cdot 10^{-8}$ sec and, when k = 1.2, it will even be reduced by $\Delta t = 2.7 \cdot 10^{-7}$ sec. This, calculating roughly, is a decrease in the particular reaction times by about 10 percent.

As an example of a neutron source we might mention a mixture of beryllium and radium bromide powder. The neutron release then takes place according to the reaction equation:

$$^{9}_{4}\mathrm{Be}(\alpha, n)\,^{12}_{6}\mathrm{C}$$

At a ratio of 3-5 g beryllium per 1 g of pure radium, such a source--if the radium is in balance with its decay products--will supply about 10^7 neutrons per second for each gram of radium.

1.3.2.3. Casing

The casing of the nuclear fission weapon generally performs three independent functions:

Reception of nuclear charge and of individual elements of detonation device;

Guaranteeing the required reaction time for energy release due to a delay in the breakdown of the weapon;

Reduction in the critical dimensions of the charge mass and better utilization of nuclear explosive through its neutron-reflecting effect.

Comparisons between the mass of the nuclear charge and the total mass of a nuclear fission weapon show that they are roughly in a ratio of 1:100. This tells us that nuclear fission weapons must have a thick-walled casing made of heavy material.

According to the data in Table 1.8, the reaction times for the chain reaction are on the order of magnitude of 10^{-6} sec. During that time, the casing must prevent the premature explosion of the charge mass and thus the immediate discontinuation of the chain reaction.

Here we can note that, considering the extremely high pressure values, such as they appear immediately after ignition, the casing's ability for temporarily maintaining the chain reaction depends only on the size of its mass. The delay in the breakdown of a nuclear weapon will thus be all the longer, the more inert the casing happens to be. Here, the type of material--apart from its density--plays a subordinate role.

It has already been mentioned that neutron losses arise due to absorption and diffusion during the chain reaction. The neutron losses caused by diffusion can be considerably reduced by designing the nuclear fission weapon's casing as a neutron reflector. Such a reflector will throw a part of the neutrons coming out of the reaction zone back into it and therefore leads to a decisive reduction in the critical mass of the fissile system and thus to greater utilization of the nuclear charge.

Specifically, the effectiveness of a neutron reflector depends on the material used and its thickness. Using the same material, the effect of the reflector increases in proportion to its thickness up to a certain boundary value.

For a standard water reflector, the optimum figures are at 6 cm. For graphite, they are 50 cm and for concrete they are about 30 cm. In the case of nuclear fission weapons, the neutron reflector must directly and firmly enclose the supercritical charge mass because even the slightest intervals will severely reduce its effectiveness. This is why the implosion principle must be considered to be very favorable.

The use of neutron reflectors is particularly important in the case of nuclear weapons with smaller detonation intensity because the neutron losses here otherwise would be very heavy.

Steel, beryllium, beryllium oxides, graphite, and their mixtures are considered particularly as neutron reflectors for nuclear fission weapons. Their effectiveness will be explained with the help of some numerical examples.

In case of a spherical arrangement, the size of the critical mass for U-235, enriched to 93.5 percent, without reflector is 52 kg. Using a water reflector, we can reduce this value to 22.8 kg and if we have a reflector consisting of beryllium oxide, it can be reduced to 8.9 kg.

For almost pure Pu-239 and a spherical arrangement of the fission materials, the critical mass is around 10 kg without reflector. A beryllium reflector with a thickness of 8 cm reduces the critical mass of Pu-239 to 4.7 kg and a reflector with a thickness of 32 cm will reduce it to 2.5 kg.

By way of summary, concerning the basic approach to the fundamental structure of nuclear fission weapons in this section, we can say that it has been possible successfully through design and other measures constantly to reduce the required size of the critical mass, to increase the efficiency, and considerably to reduce the total mass of nuclear weapons as well as their dimensions. These were decisive prerequisites for the development of nuclear warheads, for example; for various artillery systems and nuclear mines.

The nuclear bombs used against Hiroshima and Nagasaki, with a detonation intensity of 20 kt TNT, each, with a nuclear charge of only 50 kg and an efficiency of 2 percent, had a total mass of about 5 t, each. At this time we may figure that a nuclear weapon of equivalent strength will have a nuclear charge of about 5 kg with an efficiency of 20 percent and a total mass of 0.3-0.5 t.

1.3.3. Nuclear Weapons of Smaller Detonation Intensity

To make nuclear weapons with smaller detonation intensity--whose equivalents partly are extremely close to the detonation intensities of conventional ammunition--there are theoretically two possibilities. One way leads via the so-called "subcaliber nuclear weapons," while the other one leads via the utilization of nuclear explosives with a very small critical mass.

During the complete fission of all atomic nuclei in a plutonium charge of 1 kg, we get a detonation energy amount of 20 kt. It follows from this that, for every kt TNT equivalent of a nuclear weapon, we only need the complete fission of 50 g plutonium. If we assume that we can figure on an average efficiency of

20 percent, then this would be tantamount to a total nuclear explosive quantity of 250 g per kt of detonation energy. It followed from the explanations given in Section 1.3.1.3. concerning the critical mass and the numerical examples given in the following sections that, to have a chain reaction, we need a critical mass whose magnitude for Pu-239 is at least 1 kg even under the most favorable conditions. But this means that the smallest detonation intensity which can be achieved on this basis--assuming the maximum utilization of the nuclear explosive--would be about 5 kt TNT.

Basically, the reduction of the efficiency of a nuclear fission weapon does not present any great difficulties. Here we only have to do the opposite, in design terms, of what we want to achieve for the maximum utilization of the nuclear charge at "normal" detonation intensities.

First of all it is possible deliberately to slow down the process of bringing about the supercritical charge arrangement at the moment of ignition. This can be achieved among other things by dropping the principle of implosion and approaching the charge parts to each other relatively slowly.

Besides, the chain reaction can be broken off in that we counter the rapid decomposition of the nuclear charge by means of a thin casing for the nuclear weapon with only minimum inertia.

Another possibility consists in the use of neutron absorbers which lead to a reduction in the size of the neutron multiplication factor k and thus the efficiency.

All of the ways sketched here--which in practice naturally have further, considerably more complicated consequences--in the final analysis boil down to the fact that, considering a magnitude of the critical mass which we cannot go below, the chain reaction is broken off prematurely and that the detonation equivalent therefore is deliberately kept small.

Subcaliber nuclear weapons are nuclear weapons whose efficiency is below the maximum possible efficiency using the same quantity of nuclear explosive.

In this way, we can achieve nuclear fission weapons with detonatio ntensities between several hundreds of tons of TNT and several kilotons of TN h a justifiable effort.[34]

A decisive prerequisite for the mass production of nuclear fission weapons with small and very small detonation intensities on the basis of relatively poor utilization of the particular nuclear charges was the presence of sufficient supplies of fissile materials.

This is why subcaliber nuclear weapons--whose construction was basically possible from the very beginning--did not appear until the early 1960's. At that time the armament of the armies already included nuclear weapons systems for the most varied purposes with a broad scale of detonation intensities. On top of that we have the fact that methods for obtaining and processing nuclear explosives had by that time matured quite extensively.

The production of nuclear weapons on the basis of the "subcaliber principle" does not only have an uneconomical side. There is also a series of other aspects which make it appear impractical to use this method even for extremely small detonation equivalents.

According to American data, for example, in a series of tests in the autumn of 1957, nuclear charges with detonation intensities of only 0.001 kt, 0.006 kt, and 0.036 kt were tested. With such low detonation intensities, it is very difficult to determine the efficiency from the design angle. In other words, this means that, as the detonation intensity becomes smaller, the possible deviations from the standard value given will become bigger all the time. It must furthermore be kept in mind that, looking at subcaliber nuclear weapons, the share of unsplit nuclear charges out of the total quantity of radioactive detonation products is very high. But it so happens that Pu-239 is not only a very long-lived alpha-active radionuclide but moreover is biologically very dangerous and chemically highly toxic.

So far we have had only unofficial publications on the use of fission materials with a critical mass magnitude which is far below that of Pu-239, for the production of nuclear weapons with extremely low detonation intensities. Accordingly, Californium, for example, is supposed to be useful for these purposes, specifically, the isotopes Cf-294 and Cf-251.

The critical mass is given here only at 1.5 g without reference to a specific nuclide. Using this value as basis, this would mean that, figuring on a maximum efficiency of 20 percent and a minimum efficiency of only 0.1 percent, one could achieve detonation intensities in the range of 0.06-0.00003 kt.

The resultant possible weapons-engineering aspects are quite obvious. But they would be of basic military significance only if the suitable Californium isotopes could be produced in large quantities with a justifiable economic effort. This however obviously is not the case.[35]

1.3.4. Energy Release during Detonation of Nuclear Fission Weapon

The internal detonation process in a nuclear fission weapon starts with the triggering of the chain reaction due to the conversion of the nuclear charge from the subcritical to the supercritical state. The reaction time is extremely short and, as we said before, is something like 10^{-6} sec.

In our comments on the nuclear charge of a nuclear fission weapon in Section 1.3.2.1., we assumed--in deriving Formula 1.11--that, on the average, for each nucleus split, an energy amount of 200 Mev is released. This can be shown in detail if we compare the masses present before and after nuclear fission and if we compute the energy belonging to the resultant mass defect.

Among the many possibilities for nuclear fission we might make reference here to the example illustrated in Figure 1.8, below.

Table 1.9. Example of Energy Balance during Fission of U-235 Nucleus

	Mass number	Relative nuclear mass ME
(1) Sum of nuclear masses prior to fission		
(1.1) Parent nucleus U-235	235	235.0432
(1.2) Triggering neutron	1	1.00865
(1.3) Σ (1.1) + (1.2)	236	236.05097
(2) Sum of nuclear masses after fission, after completion of radioactive decay(1)		
(2.1) neodymium nucleus formed, $^{143}_{60}Nd$	143	142.90862
(2.2) zirconium nucleus formed, $^{90}_{40}Zr$	90	89.90430
(2.3) 3 fission neutrons, 3 $^{1}_{0}n$	3	3.02595
(2.4) Σ (2.1) to (2.3)	236	235.83887

(3) Size of mass defect: (1.3) to (2.4) $\Delta m = 0.2121$
Because 1 ME corresponds to an energy of 931 MeV, it follows for Δm:
$E_{s_p} = 0.2121 \cdot 931$ MeV = 197 MeV(2)

(1) The original nucleus fragments $^{143}_{56}Ba$ and $^{90}_{36}Kr$ are converted into $^{143}_{60}Nd$ or $^{90}_{40}Zr$ as a result of four successive beta decay processes. The balance given in the table thus contains the energy released as a result of the radioactive decay of the nuclear fragments.
(2) In case of a different type of nuclear fission of U-235, the energy is partly above this value so that the 200 MeV figured as mean value relate to the entire fission product mixture.

The nuclear energy of 200 Mev per split nucleus is directly distributed over the moment of detonation and the following interval of radioactive decay of the fission products. It appears here in various energy forms. Table 1.10 presents an overview.

Table 1.10. Energy Distribution during Fission of Heavy Nuclei

Energy form	Energy quantity MeV	%
In the process of nuclear fission		
kinetic energy of fission products	165± 5	82.5
kinetic energy of neutrons	5±0.5	2.5
energy of gamma radiation	7±1	3.5
In the course of radioactive decay of fission products		
energy of beta radiation	7±1	3.5
energy of neutrinos	10	5.0
energy of gamma radiation	6±1	3.0
Total energy per fission	200±6	100

The biggest part of the detonation energy is converted into thermal energy. This heats the entire charge mass to extremely high temperatures. The developing positive nuclear fragments repel each other and move away from each other at fast speed. During collision with other nuclei in the charge, their kinetic energy is primarily converted mainly into heat. The unsplit part of the nuclear charge and the fission products formed are heavily ionized due to the gamma quantums and neutrons released during nuclear fission and are in fact stripped of their electron envelope. The subsequent recombinations lead to the emission of light radiation and x-rays whose energy likewise is consumed to the extent of more than 90 percent to heat the reaction zone.

In this way, very high energy concentrations are achieved during detonation.

According to Formula 1.10., the equivalent energy amount of $2.614 \cdot 10^{25}$ Mev corresponds to a detonation intensity of 1 kt. For this we need about 50 g nuclear explosive (1.12). Assuming a density of 19 g cm^{-3}, we can calculate the corresponding charge volume at about 2.6 cm^3. For an efficiency of 100 percent, it then follows. for the magnitude of the energy concentration, that we have: $C_{Det} \approx 2{,}6 \cdot 10^{25}$ MeV : 2,6 $cm^3 \approx 10^{25}$ MeV cm^{-3} and in case of $\eta = 0{,}2$ $C_{Det} \approx 2 \cdot 10^{24}$ MeV cm^{-3}.

In general we can thus show that the initial energy concentration in nuclear fission weapons as a function of the efficiency is on the order of magnitude of 10^7 kcal cm^{-3}.[36]

Table 1.11. Comparison of Energy Concentrations from Detonations of Nuclear Fission Weapons and the Explosive TNT

	Nuclear weapon	TNT
Energy concentration, kcal cm^{-3}	10^7	1.5
Maximum temperature in reaction zone °K	$30 \cdot 10^6$	$5 \cdot 10^3$
Maximum pressure in reaction zone, atm abs	$20 \cdot 10^9$	$2 \cdot 10^5$

The maximum temperature in the reaction zone can approximately be estimated as follows:

$$T = \sqrt[4]{\frac{E_{Det}}{\theta \cdot F_{KL} \cdot t_1}} \qquad (1.19)$$

T--Thermodynamic temperature/°K
E_{Det}--Detonation energy/erg; see Formula 1.9
θ--Constant ($\theta = 5.7 \cdot 10^{-5}$ erg $cm^{-2} s^{-1} °K^{-4}$)
F_{KL}--Surface of nuclear charge/cm^2 ($F_{KL} \approx 30 \cdot q^{2/3}$)
t_1--Time/sec during which 90 percent of the detonation energy are released; see Table 1.8 or Formula 1.18.

The maximum pressure in the reaction zone can be estimated roughly as follows:

$$p = 9{,}87 \cdot 10^{-7} \cdot m \cdot k \cdot T \qquad (1.20)$$

p--Maximum pressure in reaction zone/atm abs
m--Number of particles per cm^3 gas/[1][illegible]/cm^3
k--Boltzmann constant ($k = 1.38054 \cdot 10^{-16}$ erg $°K^{-1}$)
T--Thermodynamic temperature/°K

The formula given for the calculation of the maximum pressure in the reaction zone goes back to the kinetic gas theory according to which the gas pressure is roughly proportional to the number of particles per volume unit and the thermodynamic temperature.[37] For the computation we can assume roughly the following:

$$m \geq 4 \cdot 10^{24} cm^{-3}.$$

Review Questions

1.11. What fundamental connection is there between nuclear binding energy and mass effect?

1.12. What basic conclusions concerning the possibility of releasing nuclear energy result from the diagram illustrating the average nuclear binding energy per nucleon as a function of the mass number A?

1.13. How can one explain the stability or instability of a certain nuclide?

1.14. Under what conditions can nuclear explosives be split by thermal neutrons?

1.15. What do we mean by the concept of chain reaction?

1.16. What is the influence of the magnitude of the neutron multiplication factor k on the course of energy release?

1.17. Through what design measures can the magnitude of the critical mass in nuclear fission weapons be influenced?

1.18. Explain the basic structure of nuclear weapons.

1.19. What are the ways to convert the nuclear charge from the subcritical to the supercritical state?

1.20. What is the course of the internal detonation process in nuclear fission weapons?

1.21. What are the functions of the casing of a nuclear fission weapon?

1.22. Why are subcaliber nuclear weapons "uneconomical?"

1.23. What are the energy concentrations during the detonation of nuclear fission weapons?

1.24. Under what conditions are deviations from the standard intensity given possible in the detonation of nuclear fission weapons?

1.4. Structure of Multi-Phase Nuclear Weapons and Nuclear Synthesis Weapons

1.4.1. Nuclear Synthesis as Foundation of Energy Release

As we showed in Section 1.3.1.1., there is a second, basically different possibility—nuclear synthesis—in addition to the possibility of obtaining nuclear energy through the fission of heavy nuclei.

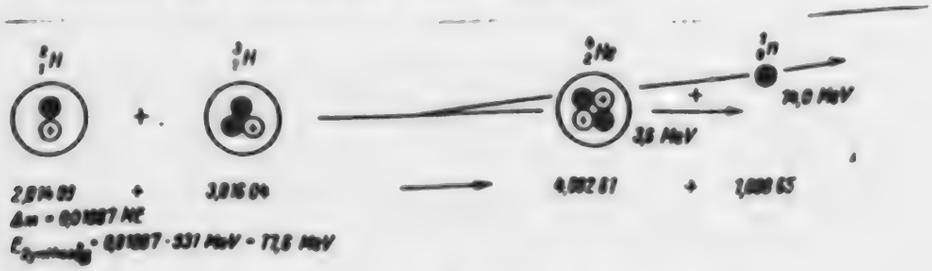


Figure 1.11. Basic diagram illustrating nuclear synthesis.

In a nucleus synthesis reaction, two atomic nuclei are combined. As a result of this nuclear fusion, there is an excited intermediate nucleus which as a rule again decays, emitting protons, neutrons, or alpha particles. Here again the released energy amount is determined by the difference in the nuclear binding energy of the original and terminal nuclei of each reaction.[38]

Table 1.12. Relative Atomic Mass of Some Important Nuclides[39]

1	2	1	2
Nuklid	relative Atommasse ME	Nuklid	relative Atommasse ME
$^{1}_{0}n$	1,00865	$^{3}_{2}He$	3,01602
$^{1}_{1}H$	1,00782	$^{4}_{2}He$	4,00261
$^{2}_{1}H$	2,01409	$^{6}_{3}Li$	6,01512
$^{3}_{1}H$	3,01604	$^{7}_{3}Li$	7,01600

Key: 1--Nuclides; 2--Relative atomic mass.

For example, for the most important nuclear synthesis reaction $^{2}_{1}H+^{3}_{1}H\rightarrow^{4}_{2}He+^{1}_{0}n$ we get an energy amount of 17.6 MeV.

During nuclear fission, less than 1,000 of the mass of the participating nuclei is converted into energy; in nuclear synthesis however--depending upon the reaction--as much as 7/1,000 are thus converted.

To overcome the electrostatic potential barriers of the nuclei participating in a nuclear synthesis reaction, they must be accelerated to a certain minimum energy. Because the size of the Coulomb forces grows along with the nuclear charge number, a blending of light nuclei can be accomplished with a considerably lesser energy expenditure than in the case of heavy nuclei. The magnitude of the potential barrier for deuterium ($^{2}_{1}H$) thus is about 0.01 MeV whereas for the lithium isotope $^{7}_{3}Li$ it is already ^{1}0.4 MeV.

If we start with the equation:

$$E = \frac{m}{2} \cdot v^2$$

and if we dissolve it for v, then we get the following expression for the average velocity needed for the nuclide that triggers the nuclear synthesis reaction:

$$v = \sqrt{\frac{2E}{m}} \qquad (1.21)$$

v--Average velocity of nuclide/m sec^{-1}
E--Magnitude of potential barrier to be overcome in the particular reaction/kg m^2 sec^{-2}.

The following applies:

$$1\ \text{MeV} = 1{,}602 \cdot 10^{-13}\ \text{J} = 1{,}6 \cdot 10^{-13}\ \text{Nm} = 1{,}602 \cdot 10^{-13}\ \text{kg m}^2\,\text{s}^{-2}$$

m--Absolute atomic mass/kg

$$1\ \text{ME} = 1{,}66043 \cdot 10^{-27}\ \text{kg}$$

For the synthesis reaction:

$$^{2}_{1}\text{H} + {}^{3}_{1}\text{H} \rightarrow {}^{3}_{2}\text{He} + {}^{1}_{0}\text{n}$$

According to Formula 1.21 we thus get an average required velocity for deuterons as follows:

$$v = \sqrt{\frac{2 \cdot 0{,}01 \cdot 1{,}602 \cdot 10^{-13}\ \text{kg m}^2\,\text{s}^{-2}}{2{,}01409 \cdot 1{,}66043 \cdot 10^{-27}\ \text{kg}}} \approx 0{,}98 \cdot 10^{6}\ \text{m s}^{-1}$$

In a similar manner, for the necessary average velocity of a deuteron to overcome the potential barrier of $^{7}_{3}\text{Li}$, we get the value $v \approx 6.2 \cdot 10^{6}\ \text{m s}^{-1}$.

The average molecular velocity v of hydrogen at a temperature of T = 300 °K is about $2 \cdot 10^{3}\ \text{m s}^{-1}$.

Because, according to the kinetic gas theory, the squares of the average velocities of the particles behave like their thermodynamic temperatures (absolute temperatures), we can--using these numerical values--determine the temperatures corresponding to the above-calculated average particle velocities:

$$v_1^2 : v_2^2 = T_1 : T_2 \qquad (1.22)$$

If we insert the corresponding values, we find that, corresponding to the velocities of the deuterons, amounting $v = 0.98 \cdot 10^{6}\ \text{m s}^{-1}$ or $v = 6.2 \cdot 10^{6}\ \text{m s}^{-1}$, we get temperatures of $T = 7.2 \cdot 10^{7}$ °K or $T = 2.9 \cdot 10^{9}$ °K.

From this we arrive at the conclusion that, in contrast to nuclear fission reactions, nuclear synthesis reactions take place only at very high temperatures.

Table 1.13. Reference Values for the Velocities of Various Nuclides and the Absolute Temperatures Corresponding to these Velocities to Overcome the Potential Barriers of $^{2}_{1}H$ and $^{7}_{3}Li$.

	1		1	
	$^{2}_{1}H$ (Potentialwall: 0,01 MeV)		$^{7}_{3}Li$ (Potentialwall: 0,4 MeV)	
	$v/m\,s^{-1}$	$T/°K$	$v/m\,s^{-1}$	$T/°K$
$^{1}_{1}H$	$1,4 \cdot 10^{6}$	$1,5 \cdot 10^{8}$	$9,8 \cdot 10^{6}$	$7,2 \cdot 10^{9}$
$^{2}_{1}H$	$9,8 \cdot 10^{5}$	$7,2 \cdot 10^{7}$	$6,2 \cdot 10^{6}$	$2,9 \cdot 10^{9}$
$^{3}_{1}H$	$8,0 \cdot 10^{5}$	$4,8 \cdot 10^{7}$	$5,1 \cdot 10^{6}$	$2,0 \cdot 10^{9}$

Key: 1--Potential barrier.

The basic problem complex in nuclear synthesis consists in the fact that the nuclei that can react must be approached to each other against their electrostatic repulsion forces to the distances of the effect of nuclear forces.

Nuclear synthesis reactions as thermonuclear reactions are based on the fact that the atomic nuclei to be fused must be imparted the kinetic energy necessary to overcome the Coulomb forces through temperature increases.

Thermonuclear reactions do not take place in the form of a chain reaction. Instead it is necessary to heat all nuclei to be made to react with each other first of all to a certain reaction temperature. These minimum temperatures depend on the particular nuclear synthesis charge and are on the order of magnitude of 10^{6} to 10^{8} °K. This kind of statement might be considered a contradiction to the values in Table 1.13. But in practice there are three reasons why the ignition temperatures of nuclear synthesis charges can be considerable among those in the table mentioned, to wit: The tunnel effect, the relative velocity of nuclei to be fused, and the statistical energy distribution of the nuclear particles in the plasma of the nuclear charge. Without going into any more detailed explanation of the tunnel effect[40] we might take a somewhat closer look at the two last-mentioned problems.

Assuming that the nuclear synthesis charge is converted to the plasma state due to energy supply from the outside, the energy of both nuclei participating in the reaction is critical for the materialization of a nuclear fusion. Because all nuclear particles present in the plasma have the same average temperature, the following condition can be derived in the most favorable case from Formula 1.21.

$$v = \sqrt{\frac{2E}{m_1 + m_2}} \qquad (1.23)$$

For the reaction (${}_{1}^{2}H+{}_{1}^{3}H$) this gives us the values $v = 6.2 \cdot 10^{5}$ m s^{-1}, $T = 2.9 \cdot 10^{6}$ °K and for the reaction (${}_{1}^{1}H+{}_{3}^{7}Li$) we have $v = 3.1 \cdot 10^{6}$ m s^{-1}, $T = 7.2 \cdot 10^{8}$ °K. Concerning the statistical energy distribution, one must keep in mind that, because of the number of countless completely irregular collisions of particles among each other, their particular momentary velocities can deviate heavily from the average value of the particle speed of the corresponding temperature [as published]. This means that individual nuclear particles can perform nuclear synthesis reactions also below the minimum temperature of the entire plasma.

The velocity, with which the individual nuclear synthesis reactions take place, depends primarily on the temperature of the charge mass. Here, the temperature is a measure for the average energy $\bar{E}$ of the nuclei to be fused. The minimum energy necessary for the materialization of a synthesis reaction is referred to as E_{min}. We get the following picture in a simplified manner: when $\bar{E} < E_{min}$ the probability of nuclear synthesis is extremely low but it is not zero. This is due to the fact that, because of the statistical energy distribution, individual nuclei have an energy which is above E_{min}. The mass of positive nuclei however will lose its kinetic energy which, on the average, is too small for nuclear reactions, due to impact or ionization processes. Here, their energy is reduced and the atomic nuclei are converted into neutral atoms due to electron capture.

In case of $\bar{E} > E_{min}$, the general prerequisites however do exist for the course of nuclear synthesis reactions. But here again the atomic nuclei lose a great part of their energy due to ionization so that the energy generated during synthesis reactions is not enough to balance out this energy loss and to keep the reaction going. From this springs the need for constant external energy supply. The reaction time for nuclear synthesis is relatively long.

When we have $\bar{E} >> E_{min}$, that is to say, in case of extremely high temperatures in the charge mass, we on the other hand get a very high effect cross-section from nuclear synthesis. During the rise in the temperature of a gas, the intensity of molecular heat movement grows quickly. At temperatures of several million degrees, the gas molecules are decomposed not only into the atoms constituting them but, in the case of the light elements hydrogen, helium, and lithium, the electron envelopes are split off from the atomic nuclei and we get a plasma consisting of freely moving atomic nuclei and electrons with a very high energy concentration. As a result, the ionization processes recede very much and the energy released due to nuclear synthesis is practically completely available for further temperature rises in the entire charge mass. It follows from this that the summary reaction time of a nuclear synthesis charge will be all the smaller, the higher its temperature is. At a certain temperature, the reaction time finally becomes so short that the reaction can take place in a lightning manner, in other words, as a detonation.

The possible utilization of certain thermonuclear reactions is determined especially by four characteristics:

The possibilities of producing the particular nuclear explosive, its cost, as well as its general physical and chemical properties;

The energy balance of the particular reaction, that is to say, the detonation energy that can be released per charge unit;

The reaction velocity of the thermonuclear reaction;

The ignitability of the nuclear synthesis charge at the temperatures generated by the weapon's fuse.[41]

Table 1.14 shows that the energy balance of the individual thermonuclear reactions differs widely. In this kind of estimate one must however not start only with the existing "pure nuclear explosives" but one must instead also look at the particular physical and chemical properties of the corresponding compounds in which the nuclear explosive is introduced into the weapon.

For example, for every kilogram of nuclear explosive during reaction (5), related to pure deuterium and tritium, we get a TNT equivalent of 84 kt. If however we were to start with the assumption that deuterium and tritium are present as heavy or superheavy water, then we would get a value of 18 kt.

The time from the ignition of a nuclear weapon to its decay is on the order of several microseconds. It follows from this that only thermonuclear reactions taking place within this order of magnitude can be used for nuclear weapons. Here naturally the generated temperatures and the densities of the charge mass also play a decisive role because the synthesis reactions in each case must take place so fast that the charge will not be decomposed prematurely. This is why, for example, we can from the very first eliminate reactions (1) and (4) because the reaction times would be too long even at temperatures on the order of magnitude of $200 \cdot 10^6$ °K.

The problems are similar regarding the ignitability of the nuclear synthesis charge. The greater the heat volume released by the fuse, that is to say, the higher the temperatures to which the nuclear synthesis charge is raised, the greater will be the possibility of also utilizing reactions with relatively long reaction times because they after all are a function of the charge temperatures (see the data in the table).

It is therefore important to insert as few ballast materials into the nuclear weapon as possible.

Table 1.14

1 Ausgangselemente			2 Kernsynthesereaktion		3 Reaktionsenergie MeV	4 Energie je Kilogrammatom kcal	5 Energie je kg Ladung kt	6 Reaktionszeit/s bei ++ $20 \cdot 10^6$ °K	$200 \cdot 10^6$ °K
7 Reaktionsbedingungen	8 Kennzeichen		Ausgangskerne 9	Endkerne 10					
$\rho > 10^3$ at $T > 2 \cdot 10^7$ °K 11 Reaktionszeit < 1...2 µs	Proton $\bullet\ {}^1_1H$ Neutron $\bullet\ {}^1_0n$ Deuterium ${}^2_1H$ Tritium ${}^3_1H$ Lithium ${}^6_3Li$	1	$\bullet + {}^3_1H$	${}^4_2He$	5,5	$125 \cdot 10^9$	42	–	0,3
		2	${}^6_3Li + \bullet$	${}^4_2He + {}^3_2He + \bullet {}^1_0n$	3,3	$75 \cdot 10^9$	13	$13 \cdot 10^{-3}$	$13 \cdot 10^{-6}$
		3	${}^2_1H + {}^3_1H$	${}^4_2He + \bullet {}^1_0n$	4,8	$22 \cdot 10^9$	23	$13 \cdot 10^{-3}$	$13 \cdot 10^{-6}$
		4	$\bullet + {}^3_1H$	${}^4_2He$	19,8	$435 \cdot 10^9$	113	–	0,5
		5	${}^2_1H + {}^3_1H$	${}^4_2He + \bullet {}^1_0n$	17,6	$405 \cdot 10^9$	61	$33 \cdot 10^{-6}$	$2,6 \cdot 10^{-7}$
		6	${}^3_1H + {}^3_1H$	${}^4_2He + 2\bullet {}^1_0n$	11,3	$261 \cdot 10^9$	43	–	–
		7	${}^6_3Li + {}^3_1H$	${}^4_2He + \bullet {}^1_1H$	5,0	$116 \cdot 10^9$	16	$25 \cdot 10^{-3}$	$25 \cdot 10^{-6}$
		8	${}^6_3Li + {}^3_1H$	${}^4_2He + {}^4_2He$	22,3	$515 \cdot 10^9$	84	$7,5 \cdot 10^{-3}$	$7,5 \cdot 10^{-5}$
		9	${}^6_3Li + {}^1_1H + \bullet$	${}^4_2He + {}^4_2He$	17,3	$399 \cdot 10^9$	50	$1,0 \cdot 10^{-3}$	$4,5 \cdot 10^{-5}$
		12 Spaltung von U-235 als Vergleich			200	$4600 \cdot 10^9$	20	–	–

Key: 1--Initial elements; 2--Nuclear synthesis reaction; 3--Reaction energy; 4--Energy per kilogram atom; 5--Energy per kg of charge; 6--Reaction time/sec at; 7--Reaction conditions; 8--Nuclear particles; 9--Original nuclei; 10--Terminal nuclei; 11--Reaction time; 12--Fission of U-235 for comparison; * The data relate to pure nuclear synthesis products; in practice it would have to be kept in mind that the reacting nuclides can be bound to certain "ballast substances"; ** The literature on the subject presents widely differing values for the reaction time; this due to the fact that the concentrations of nuclear explosives (chemical structure, density), used as basis for the computations, plays a big role.

1.4.2. Basic Elements of Multi-Phase Nuclear Weapons

There are less specific data in the literature on multi-phase nuclear weapons than on the nuclear fission weapons. Besides, their structure is considerably more complicated. This is why the following presentations must be confined to several basic viewpoints.

In contrast to nuclear fission weapons, the detonation process, when we use nuclear synthesis, as a rule takes place in several phases. Here we distinguish detonation processes which take place in two or three successive phases.

The advantages of this type of weapon consist particularly in the fact that the raw materials generally are more available and that the size of the nuclear charge is not limited upward by any critical mass.

For the synthesis phase we use mostly the nuclides $^{1}_{1}H$, $^{2}_{1}H$ (Deuterium), $^{3}_{1}H$ (tritium), and $^{6}_{3}Li$, in an elementary form or in the form of chemical compounds ($^{2}_{1}H_2O$, $^{3}_{1}H_2O$, $^{6}_{3}Li^{2}_{1}H$, $U^{2}_{1}H_3$, $U^{3}_{1}H_3$, etc.).

The first phase of the detonation process in multi-phase nuclear weapons serves for the generation of the ignition temperatures necessary to initiate the nuclear synthesis reactions. For this we use one or more nuclear fission fuses. The temperatures generated are on the order of magnitude of several tens of millions of degrees (see Section 1.3.4.).

Under this assumption, the reaction of the nuclear synthesis charge can not only be maintained but can even be speeded up through the thermal energy released during synthesis, under certain conditions. But for that we must make sure that a sufficiently large mass of nuclear synthesis charge will be made to react as a result of the course of the ignition phase. Furthermore, the velocity of heat transfer to the outside must be slow; that is to say, the heat losses must be considerably less than the heat quantity generated during the same time interval through synthesis. If these conditions are not met, then the reaction will quickly be broken off and we get a poor efficiency for the utilization of the thermonuclear charge.

Relations 1.8 to 1.10 apply fully in terms of content regarding the total equivalent of a multi-phase nuclear weapon as given in Section 1.3.2.1. In computing the number of nuclear synthesis reactions necessary for the generation of a certain detonation intensity we must however keep in mind that a part of the total energy comes from nuclear fission. This is why we have the following relationship corresponding to Formula 1.11 for the number of nuclei necessary for synthesis z:

$$z = \frac{E'_{Det} - E_{Det}}{0{,}5\,\Delta E_{syn}} \text{ nuclei} \qquad (1.24)$$

E'_{Det} --Total detonation energy from fission and synthesis

E_{Det} --Nuclear fission energy from fuse

ΔE_{syn} --Energy released during fusion of two nuclei.

We thus get the following in a similar manner for the mass of the nuclear synthesis charge related to pure synthesis substances:

$$Q' = 0{,}5\,s\left(\frac{1}{N_{A_1}} + \frac{1}{N_{A_2}}\right) \text{ kg} \qquad (1.25)$$

whereby the Avogadro constant (see Section 1.3.2.1.) in each case is related to the kilogram atoms of the nuclides participating in synthesis.

If we use Formula 1.25 however we must observe two restrictions. First of all, nuclear synthesis, with relation to the total charge, only has a certain efficiency and, besides, we must keep in mind the chemical compound in which the initial materials are present because the ballast substances must also be included in the computation of the entire charge mass. If, for example, deuterium is present in the bonded state in heavy water, then oxygen will act as ballast.

Because the structure and process of energy release in the various types of multi-phase nuclear weapons can vary greatly, we will in the following briefly describe some possible variants.

14.2.1. The Deuterium-Tritium Two-Phase Nuclear Weapon

The deuterium-tritium nuclear weapon represents the prototype of thermonuclear weapons. It came at the beginning of American development in this field while the Soviet Union obviously skipped that step.

The main components of this weapon are the nuclear fission fuse or fuses, the nuclear synthesis charge, the detonation device, and the casing. Following our earlier explanations, it is at this point only necessary to cover the energy release during the second detonation phase.

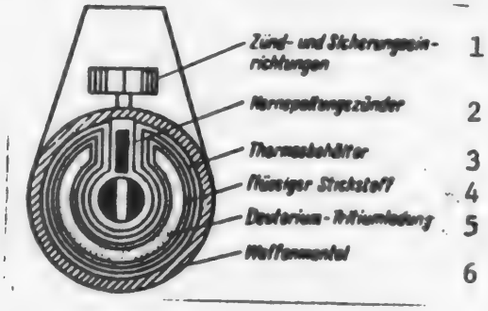


Figure 1.12. Basic structure of two-phase nuclear weapon with deuterium-tritium nuclear charge. Key: 1--Ignition and safety devices; 2--Nuclear fission fuse; 3--Thermos container; 4--Liquid nitrogen; 5--Deuterium-tritium charges; 6--Weapon casing.

A mixture of deuterium and tritium is used as nuclear explosive in this type. Both deuterium and tritium are gaseous under standard conditions. This gives us an extremely complicated construction because the required high charge density of the deuterium-tritium mixture must be achieved through liquefaction. This calls for very low temperatures (-250°C). To keep the deuterium-tritium mixture in a liquid state, it must be placed in a special thermos system. We furthermore need cooling units and evacuation systems. All of these installations however are very difficult to place in a transportable weapon because of their circumference and weight.

"The air is pumped out of the space between the walls of the thermos container and the heat influx is thus reduced. Such a vessel is placed in a vessel with the same structure into which we pour liquid nitrogen at a temperature of about -190 °C. Into the inner vessel we put liquid hydrogen, deuterium, or tritium which must be kept at a temperature of about -250 °C. But hydrogen will evaporate comparatively quickly even from those vessels."[42]

The energy release during the nuclear synthesis phase takes place according to the reaction (5), Table 1.14 (cf. ibid.):

$$^{2}_{1}H + ^{3}_{1}H \rightarrow ^{4}_{2}He + ^{1}_{0}n + 17{,}6\ MeV$$

The required ignition temperature of about 10^7 °C is generated by the nuclear fission fuses. The further course of the thermonuclear reaction is guaranteed by the energy surplus released during synthesis. From the reaction illustrated we can see that about 20 percent of the reacting synthesis charge are converted into free neutrons. The energy of these neutrons is 14 MeV.

1.4.2.2. The Lithiumdeuteride Two-Phase Nuclear Weapon

This nuclear weapon type is a design which in the literature is often referred to as "dry bomb." Here the gaseous hydrogen isotopes deuterium and tritium are completely or for the most part replaced with the solid nuclear explosive lithiumdeuteride. This yields a large number of advantages, compared to the above-described weapon, both in terms of production and in terms of weapon engineering.

Lithiumdeuteride $^{6}_{3}Li^{2}_{1}H$, which is used as nuclear explosive, like the other lithium hydrogens, is a solid, stable, and easily stored compound which can be produced on a large industrial scale relatively cheaply.

Since it is possible to make the nuclear reactions take place in such a manner that the tritium, necessary for deuterium-tritium synthesis, need not be inserted into the weapon, but is generated immediately as a result of nuclear reactions, the production costs of this nuclear weapon type decline enormously.[43] Tritium is not only difficult to make but its storability is also limited because it is radioactive and decays with a half-life of only 12.5 years.

The principle of energy release of a nuclear weapon with lithiumdeuteride charge can be illustrated schematically roughly as follows: During the first

detonation phase we have the ignition of the nuclear fission arrangement to generate the necessary reaction temperature in the nuclear synthesis charge. At the same time, a strong neutron flow develops during nuclear fission.

As a result of this, we have the following nuclear reactions:

$$\text{(a)}\ {}^{6}_{3}\text{Li} + {}^{1}_{0}\text{n} \rightarrow {}^{4}_{2}\text{He} + {}^{3}_{1}\text{H} \qquad + 4{,}8\ \text{MeV}$$
$$\text{(b)}\ {}^{7}_{3}\text{H} + {}^{1}_{0}\text{n} \rightarrow {}^{3}_{1}\text{H} \qquad + 6{,}2\ \text{MeV}$$

The tritium, developing in this fashion, reacts with the deuterium--the nuclear synthesis reactions take place as a function of the temperature of the charge mass and thus the reaction times parallel to each other--according to the well-known equation:

$$\text{(c)}\ {}^{3}_{1}\text{H} + {}^{2}_{1}\text{H} \rightarrow {}^{4}_{2}\text{He} + {}^{1}_{0}\text{n} \qquad + 17{,}6\ \text{MeV}$$

At the same time, the following nuclear reactions take place:

$$\text{(d)}\ {}^{2}_{1}\text{H} + {}^{2}_{1}\text{H} \rightarrow \begin{cases} {}^{3}_{1}\text{H} + {}^{1}_{1}\text{H} & + 4{,}0\ \text{MeV} \\ {}^{3}_{2}\text{He} + {}^{1}_{0}\text{n} & + 3{,}3\ \text{MeV} \end{cases}$$

Due to the temperature rise in the charge mass to 10^8 °K and more, caused by these reactions, the following reactions then also gain significance proportionally:

$$\text{(e)}\ {}^{6}_{3}\text{Li} + {}^{2}_{1}\text{H} \rightarrow 2\,{}^{4}_{2}\text{He} \qquad + 22{,}3\ \text{MeV}$$
$$\text{(f)}\ {}^{3}_{1}\text{H} + {}^{3}_{1}\text{H} \rightarrow {}^{6}_{2}\text{He} \qquad + 19{,}8\ \text{MeV}$$
$$\text{(g)}\ {}^{6}_{3}\text{Li} + {}^{2}_{1}\text{H} \rightarrow {}^{7}_{3}\text{Li} + {}^{1}_{1}\text{He} \qquad + 5{,}0\ \text{MeV}$$

A closer look at the nuclear synthesis reactions mentioned here in the light of Table 1.14 makes it clear that the lithium synthesis reactions require a considerably higher initial temperature for the rapid course of the overall process than is the case with the pure deuterium-tritium mixture. Here we might visualize the following solutions, among others: First of all it is possible to use a certain quantity of deuterium and tritium as so-called transition detonator; besides, solid lithiumtritide compounds are suitable for the same purpose.

By way of summary we can say that the use of solid nuclear explosives to begin with created the possibilities for the manufacture of usable multi-phase nuclear weapons because it was possible in this way considerably to reduce the dimensions and weights of the corresponding constructions.

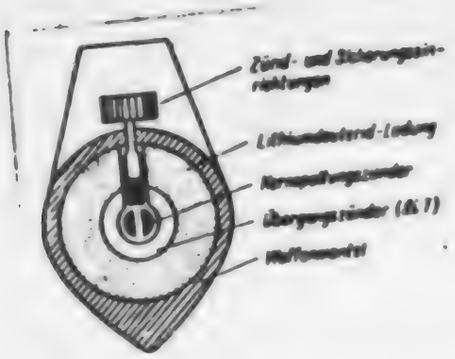


Figure 1.13. Basic structure of two-phase nuclear weapon with lithium-deuteride nuclear charge. Key: 1--Ignition and safety devices; 2--Lithium-deuteride charge; 3--Nuclear fission fuse; 4--Transition fuse (Li 7); 5--Weapon casing.

1.4.2.3. The Three-Phase Uranium Jacket Nuclear Weapon

In this nuclear weapon type, the detonation energy is generated in succession through nuclear fission--nuclear synthesis--nuclear fission. The first and second phases of this energy release basically take place as in two-phase nuclear weapons. The new thing in the three-phase nuclear weapon consists in the fact that most of the total energy of the detonation comes from the third phase, the fission of the U-238 jacket.

In our coverage of the fundamentals of nuclear fission in Section 1.3.1.2., we already pointed out that fast neutrons are necessary to split the nuclei of the uranium isotope U-238. This is also made clear by the data in Table 1.5 concerning the activation energy of U-238. Although fission neutrons with an energy of 2 MeV are released as a result of the nuclear fission of U-238, this is not enough for further nuclear fission in the manner of a chain reaction because these neutrons quickly lose energy due to elastic and inelastic collision processes so that their kinetic energy very quickly winds up below the required value of the activation energy.

The fission of a nuclear charge consisting of U-238 thus presupposes that the energy-rich neutrons, necessary for this, are supplied from the outside. The nuclear synthesis phase represents such an "external neutron source."

The detailed illustration of the nuclear synthesis reactions in Table 1.14 shows that neutrons are released during reactions (2), (5), and (6). The energy of these neutrons is 2.5 MeV in reaction (2) and 14 MeV in reaction (5).

These superfast neutrons--during deuterium-tritium synthesis, their share, as we said before, is 20 percent, by the way--are used for the fission of U-238.

Here, regarding the arrangement of the nuclear charge, the isotope mixture provided for synthesis and the U-238 which is to be split can form a uniform whole in order to keep the energy release efficiency as high as possible.

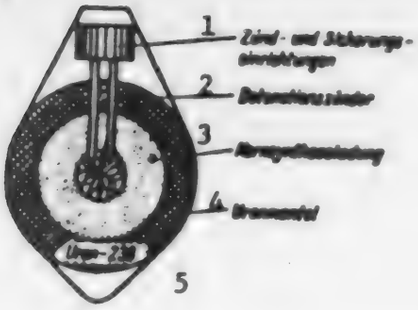


Figure 1.14. Basic diagram illustrating a three-phase uranium jacket nuclear weapon. Key: 1--Ignition and safety mechanisms; 2--Detonation fuse; 3--Nuclear synthesis charge; 4--Uranium jacket; 5--Uranium-238

Economic reasons are primarily responsible for the construction of the three-phase uranium-jacket nuclear weapon. U-238 accounts for more than 99 percent of the isotope mixture occurring in nature. It therefore can be produced cheaply and is obtained in many places as nuclear industry "waste product." Besides, long-drawn-out and expensive separation processes can be skipped here.

The following numerical example will serve to illustrate the energy release during the detonation of a three-phase nuclear weapon. But here we are dealing only with rough reference values. Each of the three energy release phases must reveal a balanced energy record and takes place by itself with a specific efficiency.

According to various data in the literature, we get the following conditions for a total equivalent 10 Mt:

To generate the necessary ignition temperature for the nuclear synthesis charge, plutonium fuses with an equivalent of 0.4 Mt are detonated during the first phase. Assuming an efficiency of 20 percent, the Pu-239 charge would have to be about 100 kg here.

For the second phase we need a synthesis charge with a deuterium-tritium equivalent of about 40 kg which supplies the required quantity of superfast neutrons. The energy share of this phase is 1.6 Mt. We assumed an efficiency of something like 50 percent. The flow of superfast neutrons from the synthesis phase is enough in order completely to split 400 kg U-238 and thus to release an energy amount of 8 Mt during the third phase. If we assume the efficiency of U-238 fission to be 10-15 percent, then a total of 4-5 t U-238 would have to be inserted into the weapon.

From what we have said so far we can deduce that Uranium-jacket nuclear weapons are suitable above all for getting detonation intensities in the Megaton range.

This assumption is confirmed among other things by a series of nuclear weapons tests during which the quantity of radioactive detonation products produced was proportional to the detonation intensities.

1.4.2.4. Multi-Phase Nuclear Weapons with Cobalt Jacket

In contrast to the function of the uranium jacket, which is used to release nuclear fission energy, the job of a cobalt jacket is not to increase the detonation energy but rather to produce additional large quantities of radioactivity. Although such constructions are very questionable from the military viewpoint, we might nevertheless present some viewpoints concerning such a weapon. Nuclear reactions as a result of which there is a powerful neutron flow can be used to trigger additional nuclear processes. Thus, it is possible, for example, if a nuclear weapon has an additional jacket of Co-59, to convert the latter into Co-60 through neutron capture. Co-60 is a beta-gamma-active radionuclide with a half-life of 5.3 years.

In a multi-phase nuclear weapon with a nuclear synthesis energy share of 10 Mt, about 1.5 t Co-60 can be produced in this fashion. This corresponds to an original radioactivity of $1.5 \cdot 10^9$ Curie or, by way of comparison, to the radioactivity of 1.5 million kg radium.

A high-altitude air burst of such a weapon would therefore lead to an extremely dangerous worldwide radioactive contamination of the atmosphere and the earth's surface which, because of the slow attenuation of radiation, would be connected with an enormous radiation exposure for large population segments. (See also the statements in Chapter 7, in this connection.)

1.4.3. Structure of Nuclear Synthesis Weapons

It follows from what we have said so far in Section 1.4.1. that minimum temperatures on the order of 10^6 °K are necessary to initiate thermonuclear reactions.

So long as one had to depend exclusively on nuclear fission fuses to generate these ignition temperatures in the synthesis charge, one could not speak of nuclear synthesis weapons, regardless of the ratio between the released detonation energies of the first and the second detonation phases.

A nuclear synthesis weapon within the meaning of the concept definition given in Section 1.1. thus exists only if it is possible to generate the necessary ignition temperatures in ways other than through nuclear fission fuses.

Some test detonations in years past and subsequent discussions in the literature indicate that such possibilities obviously exist not only in terms of theory but that they are already being used in practice to a certain degree. In looking at this kind of statement there is no question that the production of a "clean" nuclear synthesis weapon introduces a whole series of extremely complicated problems in physical-technical respects.

Kotchari[44] already pointed out that there is basically a possibility of using ordinary chemical explosives to initiate thermonuclear reactions. Reference was made here to the generation of the required ignition temperatures by means of successive hollow-charge explosions.[45]

According to available data, it is possible in this fashion to obtain gas velocities of up to 100 km s^{-1}; this would correspond to a temperature on the order of 10^6 °K.

We may, for example, estimate that the ignition of an adequate quantity of a deuterium-tritium mixture would require an external energy supply amounting to several billion Joule. But it so happens that the probability of ignition of a nuclear synthesis charge is determined not just by the amount of energy supplied. It grows, the shorter the time spent for that happens to be. If we assume an environmental pressure of about $2 \cdot 10^5$ atm abs, then we get a figure 10^{-8} sec for the time duration of ignition.

Considering the fact that known chemical explosives do not permit such extremely short ignition times, it would be conceivable to bind the energy, released by the explosive charge, for several milliseconds by means of electromagnetic fields; that is to say, to convert them into magnetic energy through field condensation and thus to get the necessary energy concentration with the corresponding short action time over several stages.

Wherein do the "advantages" of nuclear synthesis weapons reside?

The synthesis products resulting from the detonation are not radioactive. This means that, even in case of surface of underground detonations of these weapons, we need not figure on getting large areas of radioactively contaminated land. Terrain contamination is practically reduced to the neutron-induced radioactivity of the area immediately around the detonation.

It would furthermore seem to be possible in this way to produce nuclear weapons on the order of several hundred kilotons in an economical fashion. But there are as yet no further official details available on that.

In connection with nuclear synthesis weapons, we would like, in conclusion, to take up two concepts used in the literature on the subject from time to time: The so-called "clean nuclear weapon" and the "neutron bomb."

As we briefly explained regarding this problem complex in Section 1.2., both concepts came up in Western literature in conjunction with the propagation of an alleged superiority on the part of the United States in nuclear weapons development. This connection already clearly shows that most of these publications were not based on specifically natural-science facts but that their main concern was and is aimed at political and military speculations.

The question as to the "clean nuclear weapons" is relatively simple.

Basically we are dealing here with nuclear synthesis weapons, in other words, devices whose energy release is based exclusively on nuclear synthesis, or such two-phase nuclear weapons where the energy share from the nuclear fission phase is negligibly small and where, due to suitable design details--for example, a weapon jacket which will be practically indifferent regarding neutron capture--we get no further radioactive detonation products other than the neutron-induced radioactivity in the detonation area.

Here, the characteristic magnitudes of the destructive effects of the blast wave and light radiation are naturally not changed.

Concerning the "neutron bomb," this is a concept which the imperialist press did not try to define anywhere, not even making an attempt to do so. From the physical viewpoint, the main feature of such a weapon would have to consist of the fact that the entire releasable energy or at least most of it would appear as a neutron flow. This is why the question as to the neutron bomb boils down to what possibilities there are for generating the required neutron flow densities according to military viewpoints without releasing any large quantities of heat because in this case the development of a blast wave and light radiation are unavoidable.[46]

This is why methods for the generation of high neutron flow densities, through detonation-like processes, can be ruled out from the very beginning and that also eliminates processes of nuclear fission and nuclear synthesis--unless, of course, one were to consider a controlled chain reaction (reactor). Such a device however is more than doubtful for a whole series of reasons, just like the use of special electrical accelerators or neutron sources.[47]

Without going into any further details, we might observe here that a "clean" neutron weapon, not based on the detonation principle, would have only a relatively small action radius. This means that the thing that is more debatable is the version of a neutron weapon in which the neutron flow is particularly emphasized as compared to the other destruction factors. This is entirely the case, for example, with nuclear synthesis weapons, as we said earlier.

In looking into this question one must furthermore also keep in mind that the ratio between the neutron flow as a destruction factor and the blast wave and light radiation as destruction factors is shifted in favor of the former especially at extremely low detonation intensities and that, assuming the detonation altitude is properly selected, one can create conditions under which the neutron flow becomes the main destruction factor against human beings.

According to various data, for example, a nuclear synthesis charge with an equivalent of 0.05 kt and a detonation altitude of 400 m is supposed to generate an overpressure in the blast wave front on the ground amounting to a maximum of 0.03 kp cm^{-2} and a light impulse of only 0.5 cal cm^{-2} whereas on a surface of about 0.5 km^2 around ground zero we can figure on a neutron dose of 400 rem plus 80 rem of gamma radiation.[48]

By way of summary it follows that this explains both the questions of "clean nuclear weapons" and of the "neutron bomb" with the help of the basic explanations given in sections 1.4.1. and 1.4.2 for the structure and energy release of nuclear weapons.

Review Questions

1.25. What is the essence of nuclear synthesis reactions during energy release from nuclear weapons?

1.26. What conclusions can be derived from the fact that thermonuclear reactions do not take place in the form of a chain reaction?

1.27. Using Table 1.14, explain the basic prerequisites for the possible utilization of certain thermonuclear reactions in multi-phase nuclear weapons or nuclear synthesis weapons.

1.28. Explain the basic structure of two-phase and three-phase nuclear weapons.

1.5. Footnotes for the Introduction and for Chapter 1

1. Team of authors, director: Sokolovskiy, V. D., "Militaerstrategie" [Military Strategy], German Military Publishing House, Berlin, 1965, p 246.

2. "The Working Committee of the Conventional Weapons Commission, established by the UN Security Council of 4 February 1947, has drawn up the following categories for mass annihilation weapons: The atomic explosive weapons, radioactive weapons, the murderous chemical and biological weapons, as well as any other weapon which will be produced in the future and whose effects resemble those of atomic bombs and the other weapons mentioned." Quoted from E. von Frankenberg, "Massenvernichtungswaffen" [Mass Annihilation Weapons], Publishing House of the MfNV [National Defense Ministry], Berlin, 1958, p 14.

3. Some additional changes in terminology, resulting from the historical development of nuclear weapons or springing from technical and scientific aspects, will be covered in detail in Section 1.2.

4. The literature from time to time contains such formal comparisons to the effect that a nuclear weapon with a detonation intensity of 20 kt TNT would correspond to the "explosive force" of 20,000 one-ton HE bombs. This of course is approximately correct concerning energy release but does not really tell us anything significant regarding the quality and quantity of the destructive effects.

5. Grichin, N., "On Some Development Directions in Warheads for Strategic Missiles of the United States," VOYENNIY ZARUBEZHNIK, 1970, 8, pp 29-36.

6. The picture was taken from Stephane Groueff, "Projekt ohne Gnade," Bertelsmann Sachbuchverlag Reinhard Mohn, Guetersloh, 1968, p 293 or pp 294-295.

7. The table was compiled according to data taken from an "Official Report of the United States Strategic Bombing Survey, The Effects of Atomic Bombs on Hiroshima and Nagasaki," New York, 1956, in an unauthenticated translation.

8. The International Red Cross Committee for example in No 383 of REVUE INTERNATIONALE DE LA CROIX ROUGE [International Magazine of the Red Cross],

Geneva, 1951, reports for the case of Hiroshima that "among the 200 doctors in the city of Hiroshima only 30 were in a position to do their job after the bomb had been dropped; out of the 45 hospitals in the city, only three were still usable." The numbers given in the table do not contain casualties due to delayed damage.

9. Quoted from the "Official Report of the United States Strategic Bomber Command," loc. cit., pp 2-4.

10. The picture was taken from "Medical Effects of the Atomic Bomb in Japan."

11. Truman, H., Memoirs, Vol II, "Years of Trial and Hope--1946-1953," pp 6, 7; German version, 1956, Alfred Schaerf Publishing House, Bern.

12. Irving, D., "The Virus Wing," Russian, Voyenizdat Publishing House, Moscow, 1969, translation from English.

13. Blackett, P. M. S., "Militaerische und Politische Folgen der Atomenergie" [Military and Political Questions of Atomic Energy], Berlin, 1949, p 173.

14. Von Frankenberg, "Massenvernichtungswaffen," loc. cit., p 17; Frankenberg uses official comments by the then United States Secretary of War Stimson (1940-1945).

15. See also Langhans, K., "Schriftenreihe Luftschutz" [Air Raid Protection Publication Series], Interior Ministry Publishing House, Berlin, 1960, No 2, p 5 f.

16. Based on a story in the newspaper NEUES DEUTSCHLAND [New Germany], 5 November 1961, p 1 (Republic edition).

17. The following general observation can be found regarding this point in the book entitled "Nuclear Detonation," New Delhi, 1956, Russian edition 1958, p 16: "It must however be remarked that--although the energy which was released during each of these detonations and which roughly corresponded to the detonation energy of 20,000 t of trotyl--the destruction surface corresponded to only 1/10 of the surface which would be exposed to destruction if this same quantity of trotyl were to be dropped on the target in the form of conventional bombs 'weighing' 1 t, each."

18. Aleksandrov, A. P., "The Power of the Atom," PRAVDA, 24 December 1966.

19. See also von Frankenberg, "Massenvernichtungswaffen," loc. cit., pp 354-364.

20. "The confirmation of the decision put an end to the long and bitter discussions that took place in the Atomic Energy Commission (chairman: David Lilienthal) and in its consultative committee (chairman: Robert Oppenheimer) and in the course of which completely different opinions were advocated concerning the possibilities and deadlines for the

production of the hydrogen bomb." Quoted from "Nuclear Detonations," loc. cit., p 14.

21. Data on the intensity of this detonation vary widely in the literature on the subject, among other things, from 2.5 to 10 Mt.

22. "Nuclear Detonations," loc. cit., p 19.

23. "The thermonuclear device was dropped from a B-52 jet bomber. The detonation presumably took place at an altitude of 5 km. The trotyl equivalent was estimated at Mt." THE TIMES, London, 21 May 1956.

24. Quoted from TAGESSPIEGEL [Daily Mirror], West Berlin, 5 November 1960.

25. Detailed descriptions of these events can be found in DER SPIEGEL [The Mirror], Hamburg 21, 1967, Nos 46-49 and 22, 1968, Nos 5 and 6.

26. The data in the table were compiled on the basis of a large number of literature sources. We might mention the most important of them here: "The Effects of Nuclear Weapons," prepared by the United States Department of Defense, Washington, 1962; "Die militaerische Staerke der Sowjetunion," [The Military Strength of the Soviet Union], published by the SED Central Committee, propaganda and agitation department, Berlin, November 1957; Nitz, J., "Mit uns der Sieg" [Victory Is on Our Side], Berlin, 1962; Jung, R., "Heller als tausend Sonnen" [Brighter than a Thousand Suns], Bern, Stuttgart, Vienna, 1956; Buehl, A., "Atomwaffen" [Atomic Weapons], Osang Publishing House, Ban Honnef, 1968; MILITAERWESEN, Vol 196-1970; Neue Zeit, Moscow, Vols 1961-1970; "Archiv der Gegenwart" [Archives of the Present], Bonn, Vienna, Zuerich, Vols 1965-1968; "Zivilschutz" [Civil Defense], Koblenz, 1962, 5, p 162; WEHRKUNDE [Defense Science], Munich, 1962, 12, p 681; 1965, 1, p 53; 1966; 5, p 272; 1971, 3, p 163; WEHRPOLITISCHE INFORMATIONEN [Defense Policy Information], Bonn, 1970, 11, p 6; NEUES DEUTSCHLAND, Berlin, 17 October 1964, 2 November 1964, 8 December 1964; Communications from the German Institute of Contemporary History, 1965-1970.

27. "Protocol of the International Conference of Communist and Worker Parties," Moscow, 1969, Dietz Publishers, Berlin, 1969, p 15.

28. For fast information on certain fundamentals of nuclear physics, the following are recommended in particular: "Kleine Enzyklopaedie Atom Struktur der Materie" [Small Encyclopedia, Atom, Structure of Matter], VEB Bibliographic Institute, Leipzig, 1970; Lindner, H., "Grundriss der Atom- und Kernphysik" [Outline of Atomic and Nuclear Physics], Specialized Book Publishing House, Leipzig, 1969.

29. The picture was used without any change: "Kleine Enzyklopaedie Atom," loc. cit., p 138.

30. The table was taken from "Kleine Enzyklopaedie Atom," loc. cit., p 184.

31. By 1 kilogram atom A kg we mean the relative atomic mass expressed in kilograms. For U-235, the value of the kilogram atom is roughly equal to 235 kg. The Avogadro constant tells us how many atoms or molecules are present in a kilogram atom or kilomol of any chemically uniform substance. Thus we find that 235 kg of U-235 contain $6.02252 \cdot 10^{26}$ atoms.

32. Further information on this problem complex concerning nuclear reactors can be found in Dubovskiy, B. G., and others, "Critical Parameters of Systems of Fissile Substances and Nuclear Plant Safety," Atomizdat Publishing House, Moscow, 1966, Russian.

33. "Nuclear Detonations," loc. cit., p 43.

34. Detailed descriptions on subcaliber nuclear weapons can be found among others in Langhans, K., "On the Question of Subcaliber Nuclear Weapons," MILITAERWESEN, 4, 1960, 2, pp 347-354.

35. According to a story in No 12, 1969, of the magazine URANIA, on page 39, the price of 1 g of Californium is presently reported to be $1 billion; it is supposed to take several years before 1 g of this chemical element can be produced annually.

36. In looking at the energy concentration, the detonation intensity plays a role only inasmuch as it must be assumed that various detonation intensities also reveal different efficiencies.

37. One cm^3 of nuclear charge contains about $5 \cdot 10^{22}$ atoms. When $\eta = 0.2$, 10^{22} nuclei are split off from that.

Each fission accounts for about 400 particles (nuclear fragments, neutrons and, mostly due to ionization, electrons). Both Formula 1.19 and Formula 1.20 are relatively independent of the detonation intensity. This is why the figures given in Table 1.11 for the maximum temperature and the maximum pressure in the reaction zone can serve generally to describe nuclear fission weapons. In the reaction zone we have the nuclear charge in the form of a plasma; this is why the electrons can be treated according to the kinetic gas theory. We must however not overlook the fact that widely differing values are being given in literature regarding the degree of ionization. This creates uncertainty when it comes to making a clear determination of m and thus also p.

38. The concept of nuclear synthesis reaction is used below both for processes of pure nuclear fusion and processes of nuclear decomposition reactions in which the nuclear mass of the developing nuclide is between those [masses] of the initial nuclides. Thermonuclear reaction and nuclear synthesis reaction are used as synonymous terms.

39. The values in this table were taken from Lindner, H., "Grundriss der Atom- und Kernphysik," loc. cit., p 99.

40. See ibid., p 136.

41. On these questions, see Neyman-Sadilenko, "Mehrphasenkernwaffen" [Multi-Phase Nuclear Weapons], German Military Publishing House, Berlin, 1961, pp 86 ff.

42. Ibid., p 76.

43. According to various literature data, 1 kg of tritium cost about $500 million in the United States at the beginning of development work.

44. See also "Nuclear Detonations," loc. cit., p 21.

45. Some comments on this problem complex can be found in A. Peyron, "Method and Device for the Ignition of a Nuclear Weapon," Patent No 1,350,078, dated 16 December 1963, Ministry of Industry of the French Republic; Hajek, "The Possibility of Nuclear Reactions by Means of Hollow Charges," WEHRTECHNISCHE MONATSHEFTE [Military Engineering Monthly], 57, 1960, 1, pp 8-21.

46. Generally understandable and summarizing statements on this problem complex can be found among others also in Calder, J., "What Do We Know about the Neutron Bomb?" INTERNATIONALE ZIVILVERTEIDIGUNG [International Civil Defense], Geneva, July-August 1961, Nos 73-74, p 1.

47. In making such statements, one must naturally keep in mind that one cannot rule out the fact that new physical methods of neutron production via the "cold way" may exist although they are not yet generally known. But this is less probable in this particular case.

48. A general comment on this problem complex can be found among others also in KRASNAYA ZVEZDA of 12 June, p 4, and 13 June, p 3, 1961. Colonel Glamov here covers the development of the neutron bomb and the Californium bomb. The latter is supposed to be a derivation of the neutron bomb. Reference is made here to additional possible interpretations of the concept "neutron bomb."

2. Outward Phenomena of Nuclear Weapon Detonation

2.1. Most Important Features of a Nuclear Weapon Detonation

The processes and phenomena connected with a nuclear weapon detonation are very multilayered and extraordinarily complicated. Only a part thereof is visible or can be perceived with the human sensory organs.

The impression which an observer gets regarding a specific detonation will among other things always depend on his position and his distance from the place of detonation and what observation means and possibilities he had available.

Regardless of that, the features of a nuclear weapon detonation are determined or influenced primarily by the detonation intensity, the detonation type, the weather and terrain conditions, and some other factors.[1]

In Hiroshima, the detonation of the 20-kt nuclear bomb took place at an altitude of 600 m. At the moment of the detonation, the detonation area was lit up glaringly by a jet of flame that was visible far away. After 0.1 msec, a fireball with a diameter of about 30 m developed. Its temperature was 300,000 °K and thus exceeded that on the surface of the sun about 50 times.

The fireball grew and rose rapidly. After 1 sec, it had reached a diameter of 300 m. The average velocity of upward movement was 100 $msec^{-1}$. After about 10 sec, the fireball was completely extinguished. Most of the light radiation was radiated over a period of 3 sec.

As a result of the extinction of the fireball, the detonation products were condensed and formed a characteristic, mushroom-shaped detonation cloud whose stem consisted of dust, ash, and masses of earth that had been swept up due to the suction resulting from the upward movement of the fireball or the detonation cloud. After 4-5 min, the detonation cloud had a diameter of 3 km and after 7 min reached an altitude between 10 and 15 km. The cloud remained stationary over the detonation area in this shape for some time and then began to break up due to the influence of high-altitude wind.

A dense, nontransparent dust and smoke cloud rose shortly after the detonation directly in the detonation area.

The detonation was accompanied by an extremely loud, shrill, and unpleasant noise.

A detonation in the Megaton range will develop in a manner similar to the features described here.

In November 1952, the United States exploded a nuclear weapon with an equivalent of 5 Mt in the region of the Marshall Island in the Pacific Ocean. The explosion took place right above the surface. One small island was completely obliterated. The diameter of the resultant crater was 1.5 km; its maximum depth was 50 m. Its volume was estimated at 0.05 km^3. The weight of the dirt and slag masses expelled by the detonation was about 50 million Mp.

The fireball's maximum diameter was 4 km. The detonation products rose to an altitude of 40 km and the detonation cloud, which developed roughly at an altitude of 15 km, reached a horizontal extent of 160 km.

In 1946, the United States conducted a 20-kt underwater detonation in the region of Bikini Atoll.

The detonation depth was 15 m. The water masses expelled by the detonation formed a water column which after 1 minute reached its maximum dimensions with a height of 2.5 km and diameters of 500 m at the base as well as 2,500 m at the cap. This corresponds to a water mass weighing 1 million Mp.

The most important external features of a nuclear weapon detonation include the fireball, the detonation cloud, and the detonation crater. Whether the detonations take place over land or over water plays a big role in the development of these features. It is furthermore necessary especially to consider the influence of the detonation intensity and the detonation altitude or depth. Conversely, it is naturally also possible with the help of these characteristics to make certain statements concerning the determination of the initial data of enemy nuclear weapon strikes.

2.1.1. The Fireball

On the basis of the extraordinarily high energy concentration and the fact that about 80 percent of the detonation energy originally appeared in the form of heat, the nuclear weapon is almost instantaneously vaporized during the detonation, whereby the gaseous detonation products initially hardly exceed the prior weapon volume and a fireball is formed.[2] In surface and underground detonations (underwater detonations), the fireball contains large quantities of vaporized and melted soil material (water) in addition.

The fireball from a nuclear weapon detonation represents a glaring bright, more or less spherical structure consisting of a cloud of glowing gases (plasma).

Because of the high energy concentration during the initial phase of its development, the fireball is the cause for the origin of a blast wave as well as, during its existence, the source of very intensive light and heat and radiation as well as an electromagnetic impulse.

The observation of the fireball's development is of interest in describing the destruction factor represented by light radiation, in explaining the origin and spread of the blast wave, and in characterizing the various detonation types.

The fireball's development can be broken down schematically into two periods of two stages, each (see Figure 2.1).

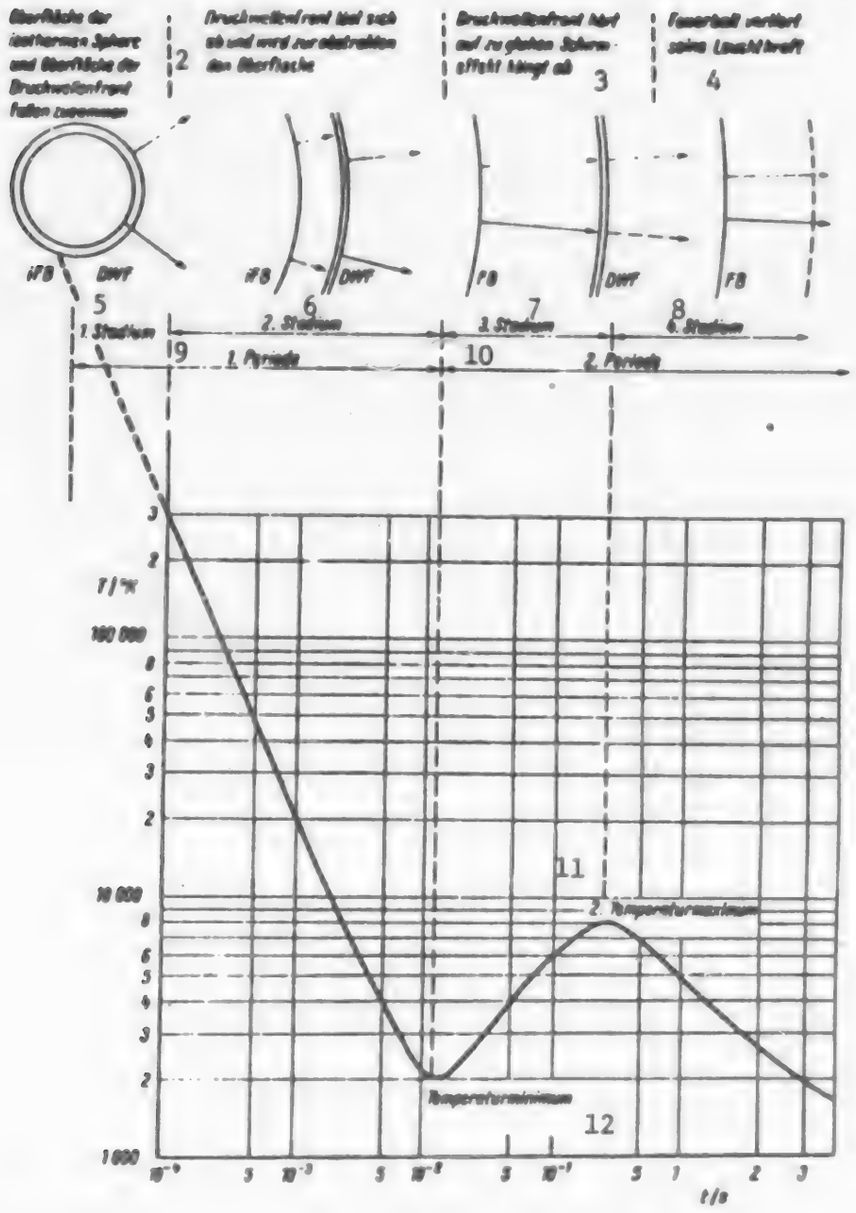


Figure 2.1. Diagram illustrating the development of the fireball and the temperature curve at the surface of the particular effective sphere.
Key: 1--Surface of isothermal sphere and surface of blast wave front coincide; 2--Blast wave front separates and becomes radiating surface; 3--Blast wave front stops glowing, screening effect fades; 4--Fireball loses its illuminating power; 5--1st stage; 6--2nd stage; 7--3rd stage; 8--4th stage; 9--1st period; 10--2nd period; 11--2nd temperature maximum; 12--Temperature minimum; DWF--Blast wave front; iFB--Isothermal fireball.

During the first stage, the fireball represents an isothermal sphere; that is to say, a ball in which the temperatures are equally high everywhere. The expansion speed of the fireball and the speed of the blast wave are equal. Because of that, the surface of the fireball and the surface of the blast wave front coincide. As the fireball grows, the temperatures in the isothermal sphere drop. At a certain point in time after the detonation, by which time the temperature has dropped to about 300,000 °K, the blast wave front moves faster than the front of the isothermal sphere and the blast wave front is separated from the fireball.

This marks the beginning of the second phase.

The cause of the fact that, during this second stage, the energy equalization with the surrounding medium takes place faster by means of the blast wave than via light radiation--a phenomenon which seems to conflict with general experience--can be explained in a simplified manner in the following way.

As we know, the intensity and wavelength of the light quantums radiated by a glowing body depend on the temperature of the radiating surface, in this case, on the fireball's surface temperature. In the high temperatures present in the isothermal sphere, most of the photons are found in the outermost part of the UV spectrum range.

Because the absorption of the light quantums by the air components again grows as their wavelength decreases, it follows that light radiation during this stage of the fireball's development has only an extremely small average free path distance. Light with wavelengths of less than 186 nm is on the average completely absorbed in the air after only 0.01 cm. This explains both the slow transport and isothermal state of the fireball.

Because of the great pressure gradient and the resultant fast velocity of the blast wave front and the air in this front, the air is so heavily compressed that, due to the developing friction, it is heated to temperatures of more than 2,000 °K and is thus made to glow. The fireball now consists of two separate concentric areas; the inner, isothermal sphere, and the shining blast wave front. The shining blast wave front is impermeable for the light radiation emitted from the isothermal sphere and therefore in this developmental stage appears as radiating surface of the fireball. If we therefore look at the temperature curve at the particular visible shining ball surface, appearing as a fireball, then a temperature minimum is reached during this stage. This is the end of the first period of the fireball's development.

The third stage is characterized by the fact that the overpressure in the wave front declines rapidly as the blast wave spreads further. This means that the wave front stops shining and ceases to be the radiating surface of the fireball. Parallel to that, the surface of the glowing detonation products gradually again appears as the effective surface of the fireball. The surface temperature rises to a second maximum.

The subsequent fourth stage and thus the second development period finally are terminated by the fact that the fireball is further cooled due to expansion and energy radiation and is finally extinguished.

The characteristic magnitudes of the fireball from a nuclear weapon detonation in the atmospheric layer near the earth are determined by the detonation intensity and the detonation altitude.

The duration of the first period and the radius of the fireball grow as the detonation intensity increases while the temperature minimum, appearing at the end of this period, goes down, the greater the detonation intensity.

The duration of the first development period t_1 of the fireball can by way of approximation be calculated with the help of the following empirical formula:

$$t_1 = 3{,}2 \cdot 10^{-3} \cdot q^{1/2} \quad s \tag{2.1}$$

The fireball's radius, during the passage of time t_1, as a function of q, follows the relationship:

$$R_1 = 235 \cdot q^{0{,}31} \cdot t^{0{,}36} \quad m \tag{2.2}$$

whereby we must have $t < t_1$.

The temperature minimum at the end of the first period can be calculated as follows:

$$T_{min} = 4{,}5 \cdot 10^3 \cdot q^{-0{,}1} \quad °K \tag{2.3}$$

q--detonation intensity/kt; t--time since detonation/sec.

Both during the first period of its development and during its second period, the fireball differs more or less from a sphere as a function of the detonation conditions. Major differences appear between the horizontal and vertical dimensions especially in connection with smaller detonation intensities. In the literature therefore data for the second period are often related to a so-called "equivalent fireball," that is to say, to a fireball whose volume corresponds to that of the real fireball.

Table 2.1. Reference Values for the First Period of the Fireball from a Nuclear Weapon Detonation (1)

q/kt	t_1/ms	R_1/m	T_{min}/°K
1	3	35	4500
10	10	80	3500
50	22	150	3000
100	32	190	2800
500	70	340	2400
1000	100	440	2200
5000	230	790	2000

(1) The figures given in the table were calculated according to formulas 2.1 to 2.3. They apply to the undisturbed development of the fireball.

This problem complex plays a certain role specially in the determination of the detonation intensity of a nuclear weapon due to technical devices by means of the dimensions of the fireball as well as during the origin of the electromagnetic impulse. In this connection it might be pointed out that the fireball is illustrated by radar sets, at least when the fixed-target suppression is turned off.

The fireball's light duration (radiation time) can be determined approximately with the help of the following formula:

$$t_L = q^{1/3} \text{ s} \qquad (2.4)$$

The fireball's radius during the second period, that is to say, during time t_2, as a function of q, follows the relationship:

$$R_{equ} = 93{,}5 \cdot q^{0.28} \cdot t^{0.17} \text{ m} \qquad (2.5)$$

whereby we must have $t_1 < t \leq t_L$.

Table 2.2. Reference Figures for the Second Period of the Fireball from the Nuclear Weapon Detonation(1)

q/kt	t_L/s	R_{equ}/m
1	1,0	90
10	2,2	200
50	3,7	350
100	4,6	440
500	7,8	750
1000	10	950
5000	17	1650

(1) The numbers apply to an undisturbed fireball development.

The fireball is deformed at the end of the second period. Its horizontal dimension then is about 2.5 R_{equ}.

The illuminating power of the fireball depends little on the detonation intensity. This is due to the fact that the brightness is a function of the surface temperature which rises only relatively slowly as the detonation intensity grows.[3]

The detonation altitude essentially influences the shape of the fireball and thus also its dimensions. At detonation altitudes of $H_D > 100 \cdot q^{1/3}$ m the fireball has a spherical shape. Starting at $H_D < 100 \cdot q^{1/3}$ the fireball increasingly takes on the shape of a hemisphere, that is to say, it is flattened out at its underside. At a detonation altitude of $H_D < 35 \cdot q^{1/3}$ m, the fireball finally touches the ground.

At H_D = 0 m we speak of a contact detonation where the fireball initially is completely hemispherical but then it immediately extraordinarily deforms. The detonation altitude, at which the fireball from a nuclear weapon detonation of a certain intensity touches the ground, cannot simply be determined by comparison with the particular maximum fireball radius.

This is due to the fact that the fireball reaches its maximum extent only during a certain period of time, that it moves upward at the same time while it spreads out, and that it is furthermore flattened out along its underside by the blast wave which is reflected along the earth's surface. It is generally assumed that no contact takes place between the fireball and the earth's surface with a high degree of certainty if the detonation altitude at least corresponds to the size of the fireball's radius at the time of the second temperature maximum ($t(T_{max}) = 0.065 \cdot q^{t/3}$ s). According to Schrader[4] the following empirical formula then applies to the dependence between the fireball's radius according to Formula 2,5 when $t = t(T_{max})$ and the detonation intensity q:

$$\frac{R_1}{R_2} = \left(\frac{q_1}{q_2}\right)^{2/3} \qquad (2.6)$$

Further considerations regarding the fireball can be found in Section 4.1 in connection with the treatment of the general characteristic of the destruction factor which we call light radiation.

2.1.2. Detonation Cloud

A cloud characteristic of the particular detonation type is formed a few minutes after a nuclear weapon detonation.

The radioactive detonation cloud has the shape of a mushroom during detonations in which the fireball at least partly reaches the atmosphere. It consists of the detonation cloud as such (the condensation cloud) and the stem which is formed of earth and slag or water masses that are whirled upward.

The detonation cloud is formed from the fireball which gradually becomes colder due to enlargement and energy radiation. Depending on the type of detonation, it consists mostly of the condensed wreckage of the nuclear weapon, including the radioactive detonation products, atmospheric dust, and vaporized as well as unvaporized ground material or water. It is typical of this condensation cloud that it above all contains small and very small particles (aerosols). The quantity and type of soil material (water), which is swept upward by the suction effect hose that is formed due to the fast climbing speed of the fireball, depend on the detonation intensity, the detonation altitude or depth, and the nature of the detonation area. Here we are dealing primarily with large and larger particles which, after detonation, rapidly fall back into the detonation area and its immediate vicinity.

Because the radioactive detonation products in fact are to be found exclusively in the condensation cloud, the character of the terrain's radioactive